QCD ENCORE PROJECT

Mechanical Masters

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June 10, 2009

Abstract:
Mechanical Masters is developing assistive technology which will reduce barriers to employment advance for individuals with disabilities by increasing their productivity in the work place. The specific task to be addressed is the installation of three different sized O-rings onto the component parts of a syrup dispenser for a fountain drink machine. By producing a device that will reduce O-ring installation to fewer than 4 steps per O-ring, worker productivity is to be increased by 30-40% so that the customer can meet the target of 30,000 part assemblies per day. In order to select the most effective design, Mechanical Masters will be developing and prototyping two concepts simultaneously before making the final design decision. Mechanical Masters developed three distinct prototypes, each designed to assist in the installation of three separate O-rings onto three different parts with unique geometries. These prototypes were tested to determine that they met the project target specifications. Although repeated testing indicated that the prototypes met the required performance specifications, the customer's feedback indicated that the devices were not adequate for the workers' needs. The customer indicated that the devices needed to be made more user friendly for the workers and additional features needed to be added to the devices in order for the customer to actually use the devices. We recommend that any future action taken for this project define more accurately and precisely the customer's actual needs and develop design concepts more conformable to those customer needs.

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1.0 Introduction

A disability is defined as a “disadvantage or deficiency, especially a physical or mental impairment that interferes with or prevents normal achievement” [1]. According to this definition, normal achievement includes entering or progressing in the work force.

According to 2006 data from the American Community Survey, published by the U.S. Census Bureau, over 15.1% of the U.S population who are five years or older have at least one disability. In the age range of 16-64 years old, nearly 24 million persons have disabilities, and only 37.2% of these persons were employed. For comparison, in that same year, over 60% of the general US population 16 years of age or older were employed. The data also suggest that disabilities are a more pronounced problem for females because only 34.2% of females aged 16-64 had employment compared to 40.2% of males in the same age group [4].

These data certainly suggest that unemployment is a more serious problem for persons with disabilities than for the general US population. In fact, the income levels for persons with disabilities is significantly lower than the income levels for the general US population; indeed, the median income for a person with a disability in 2006 was only 60% of the median income level for the general population [4].

The U.S. Census bureau also reports data on disabilities on the state level. According to the data, the state with highest proportion of persons with disabilities is the state of West Virginia. As of 2006, nearly 22% of the population ages 21-64 had at least one disability, well over the national average [4]. Details on these data are included in **Appendix A**. This information is particularly relevant for the design project Mechanical Masters is working on since the customer we are working with is located in the state of West Virginia, as described more fully in Section 1.4.

1.1 Project Definition

ME 470/471/472 is a senior capstone design project for the mechanical engineering undergraduate program at the Russ College of Engineering and Technology at Ohio University. This capstone design project is a year-long team project for students majoring in mechanical engineering at Ohio University.

The senior capstone design project sequence for the year 2008-09 is focusing on the NISH National Scholar Award Workplace Innovation & Design competition and the design teams are expected to compete in the 2009 NISH competition. This competition focuses on designing “creative technological solutions to barriers that prevent people with disabilities from entering or advancing in the workplace” [10]. For this project, student design teams are encouraged to work with nonprofit agencies (NPAs) who employ persons with disabilities, particularly those NPAs which are affiliated with NISH.

There are seven distinct topic areas which NISH seeks to address through this competition. The seven areas are listed here (taken directly from the NISH competition description [10]):

"**1. Technology for Special Populations**, cognitive disabilities, learning disabilities, developmental disabilities, low
vision/blindness, hearing impairments, dysphasia, elderly interventions, service delivery programs
2. Augmentative and Alternative Communication, communication boards, computer-based
communication devices
3. Computer Access and Use, innovation in software and hardware, training strategies, integration of
computer technologies, alternative access
4. Environmental Accommodation, Environmental Control Unit systems, work-site modifications,
ergonomics, farming and other rural interventions, universal design of products, places, and systems
5. Functional Control and Assistance, rehabilitation robotics, functional electrical stimulation, prosthetics
and orthotics
6. Service Delivery, technology transfer, telerehabilitation
7. Seating and Mobility, seating and wheelchair interventions, seat pressure measurement, transportation issues"

1.2 Project Scope and Goals

There are several goals which we as a team seek to achieve as the result of this project. Some of these goals are the result of the type of project we are to select as outlined in Section 1.1 while others are the more general goals we have as a team for completing our capstone design project.

The general purpose of the NISH competition is to increase the employment opportunities of specific individuals with disabilities by increasing their work productivity. By creating assistive technology designed to overcome the barriers caused by the disabilities, the NISH competition seeks to advance these individuals in the workplace. If the individuals are without employment but are seeking employment, the NISH competition seeks to provide the individuals with the ability to find the employment that they seek.

There are several reasons why the Senior Design Capstone Project is focusing on the NISH competition this year. First, entering such a competition allows the teams to tackle real world design problems and to work with real clients. Second, by centering the project around helping individuals with disabilities, the class is able to give back to the local community and provide a community service.

This Capstone Project also has several goals aimed at developing the students' professional skills by specifically addressing their ability to work well with other people in the same team and by improving their technical skills by providing an opportunity to use their technical skills and knowledge in the design process.

The purpose of the Capstone Project is four-fold, according to a description of the Program Educational Objectives Statement [11]:

"1. Prepare Graduates for engineering careers and advanced education
2. Graduate mechanical engineers with technical skills
3. Graduate mechanical engineers with skills to perform in the work environment
4. Graduate mechanical engineers who are informed and aware of contemporary issues and the impact of engineering on society."

1.3 Initial Needs Statement

There is a need for assistive technology devices that reduce barriers that prevent persons with severe disabilities from entering or advancing in the workplace. Devices are needed to address environmental accommodation, functional assistance, and mobility issues for people with cognitive disabilities, developmental disabilities, and physical impairments (vision, hearing and mobility) [10].

1.4 Customer Selection

The company to be assisted is SW Industries, a branch of SW Resources located in Parkersburg, West Virginia. They provide services to the business community through the talents of individuals with disabilities in the Mid-Ohio Valley. Many of these services are packaging, shipping, or light assembly projects that some businesses find tedious, and it is one of these light assembly projects that will be looked at for better alternatives. SW Industries, the largest division of SW Resources [2] and the division which contracts with state and federal governments as well as local and national businesses [3], is the division of SW Resources that we are specifically working with for our project.

As mentioned in the introduction, the percentage of the population with disabilities is unusually high in West Virginia, so we are providing a service for a geographic area where the need for assistive technology is arguably the greatest.

2.0 Customer Needs Assessment

It is very important to find out as much about SW Resources as possible so that we could accurately and completely assess the specific needs of our customer and the persons employed by our customer. Our project is to develop a product that is satisfactory to our customer; therefore, our initial goal was to accurately identify the customer's specific needs. The measure of our success for this design project is how well SW Resources decides our project fits the needs of its employees.

2.1 Customer Project Selection

In order to do accurately determine our customer's needs, our group met with SW Resources several times to get an overall view of what needs to be accomplished and to view the resources available at their facility. The first time that we met with SW Resources, we toured their facilities and overviewed several of the different divisions of the company including SW Industries, Mail Plus, and SW Designs. During this trip, we met with several employees in management positions and also met with several of the employees who have disabilities. The managers showed us several of the projects which SW Resources was currently engaged in as well as several projects which they are about to begin. The observation notes which we took during this meeting are included in **Appendix B**.

From this meeting we were able as a team to discuss our options and decide which project we would choose if SW Resources became our customer. The project which we selected would determine the specific customer needs since SW Resources is involved in a diverse range of projects and its employees have a large range of disabilities.

After this first preliminary meeting with SW Resources, we decided that we would like to work with them and we selected their "Widget Project," the assembly of a syrup dispenser for fountain drink machines used by restaurants. We specifically decided to work on the O-ring assembly

2.2 Customer Needs Identification

After our project selection, we determined the customer's needs given the observations we had made during our visits of SW Resources facilities. The following tables show a list of customer needs that our group will strive to meet and the order of importance of these needs. **Table 2.2.1** gives a general listing of customer needs.

Table 2.2.1 - Initial Customer Needs List Obtained From Interviews and Observations

Versatile (covers a variety of disabilities)
Sanitary
Simple
No maintenance required
Safe
Affordable
Cuts assembly time
Lightweight/compact

After we identified the general customer needs, we created a hierarchal list of the customer needs as a team so that we could rank the needs in order of importance. This hierarchal list of customer needs would provide us with the basis for our future weighting of customer needs. **Table 2.2.2** gives this hierarchal list.

Table 2.2.2 - Hierarchal Customer Needs List

1. Safety
1.1 Low Risk for hand operation
1.2 Low noise
1.3 No sharp edges
1.4 Enclosed mechanical components
2. Sanitary
2.1 Parts will not rust or deteriorate
2.2 Easy to clean on a daily basis
2.3 Lubrication must be enclosed if used
2.4 Water proof
3. User Friendly
3.1 No more than 2-3 steps involved
3.2 Easy for anyone to understand
4. Cost
4.1 Minimal cost
5. Size
5.1 Able to fit in a utility sink
5.2 Easy for a single individual to carry
5.3 Fits on a standard table
6. Low Maintenance
6.1 Easy to maintain
6.2 Low maintenance cost

2.3 Weighting of Customer Needs

We employed the Analytic Hierarchy Process (AHP) to determine the relative importance of each of the six customer needs identified in **Table 2.2.2** shown previously. According to the organization responsible for defining this process, AHP "is a structured method for helping people deal with complex decisions. It provides a comprehensive and rational framework for structuring a problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions" [12]. This method allows people to determine benefits, costs, and dependence during the decision making process. We employed this method to determine quantitatively the order of importance of the six customer needs.

Table 2.3.1 shows the results of our analytical hierarchy process of weighting these six customer needs. We determined the individual relative weightings in columns 1-6 by group consensus, that is, as a team we decided unanimously what the relative importance of safety was to sanitary, etc. We then computed the weights for each need. As can be seen from the table, sanitary was determined to be the most important identified need.

Table 2.3.1 - Analytical Hierarchy Process Weighting of Customer Needs

	Safety	Sanitary	User Friendly	Cost	Size	Low Maintenance	Total	Weighting
Safety	1.00	0.75	1.13	2.00	2.00	8.38	8.38	0.20
Sanitary	1.33	1.00	1.33	2.50	2.50	10.66	10.66	0.26
User Friendly	0.89	0.75	1.00	2.00	1.75	8.14	8.14	0.20
Cost	0.50	0.40	.50	1.00	0.80	4.00	4.00	0.10
Size	0.50	0.40	.57	1.25	0.67	4.39	4.39	0.11
Low Maintenance	0.67	0.50	.57	1.25	1.00	5.49	5.49	0.13

3.0 Revised Needs Statement and Target Specifications

Normally we would observe the current processes SW Resources uses to accomplish the task of O-ring assembly so that we could accurately identify the specific need of the customer. However, since SW Resources has not, to date, begun the actual assembly and installation of the O-rings for the syrup dispenser, we could only observe and collect data based on their proposed methods. Thus, any data which we have collected thus far for worker productivity levels is tentative and is only a crude estimate. The data we collected on worker productivity is included in **Appendix B**.

Figure 3.0.1 shows the proposed floor layout plan for the O-ring installation. According to this plan, all three O-rings are to be assembled at separate stations. Once the O-rings are installed on each of the three parts, the parts are sent to a station where the entire syrup dispenser is assembled. This plan proposes that the method for installing O-rings is purely manual. The O-rings and the parts are provided to the employee by a supervisor. The O-rings and parts are initially in separate containers and it is the task of the employee to take both out of their respective containers, install the O-ring manually while holding the part and to deposit the part with the installed O-ring into a part bin which will transport the part to the final assembly stations.

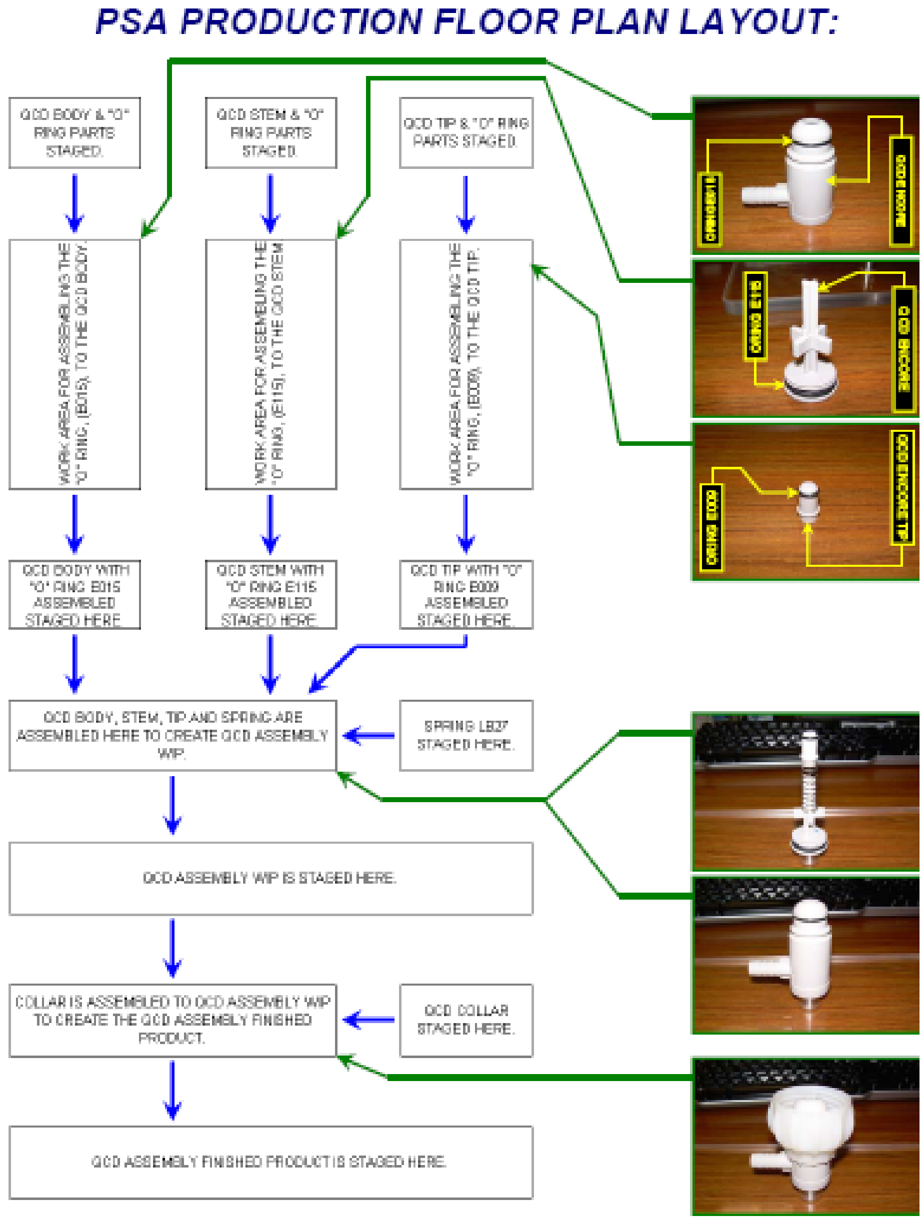

Figure 3.0.1. Production Floor Plan Layout from SW Resources [13]

3.1 Revised Needs Statement

SW Resources employees with varying levels of disability need a device to assist with handling and installing O-rings. We are targeting our design towards employees with less severe disabilities to improve their productivity. In order to meet SW Resources' production goal of 30,000 parts assembled per day, a total of 80 SW Resources employees must be able to use our design to install a total of 90,000 O-rings per day.

3.2 Target Specifications

SW Resources employees with varying levels of disability need a device to assist with handling and installing O-rings onto their respective components for the syrup dispenser for fountain drink machines. Target Specification can be found in **Table 3.2.1**.

These target specifications were drawn up by the team and later sent to the customer for approval. We knew that the device would be most effective for the customer if the per unit cost were less than a couple hundred dollars so we determined that the target specification for the cost would be $200. Since the device would need to be sanitized regularly, we decided to limit the materials used for the device to ones which were rust and water proof. If our device were to improve productivity, we would have to use 3 steps or fewer for the O-ring installation.

The size of the device also was of concern to our team. We wanted the device to have a low enough weight that a single person could easily and comfortably carry it, and we wanted the device to be able to fit inside the sinks available at the customer's facilities. (Initially we targeted a maximum volume of 3 ft^3 but realized that the correct volume should be 1.5 ft^3, the volume of the sinks the customer has.) The target specification for the aspect ratio is the ratio between the width of the device to the height or depth. Thus, according to this specification, the width should not be more than three times the height or depth of the device.

Table 3.2.1

Description	Specification
Material Property	Rust and water proof
Simple Operation	4 or fewer steps
Cost Effective	< $200
Lightweight	< 30 lbs
Compact size	< 1.5 ft^3
Installation time per O-ring	4 seconds
Productivity increase	> 30%
Input force	< 15 lbsf.

4.0 External Search

In order to generate design concepts that were relevant to our selected tasks and that met general regulations and requirements, we performed several broad searches of applicable patents, a literature search of O-ring installation, and government and industry standards and constraints.

4.1 Problem Clarification

The installation of the O-rings contains three major obstacles due to the three different O-ring sizes. The design required will need to be applicable for all three parts. However, since each of three O-rings have unique features, we considered the possibility that three unique designs (one unique design for each O-ring) may need to be pursued. We determined that at most two unique

designs would be needed. After developing initial ideas, it was a team decision to develop multiple designs suitable for each O-ring. The design required will support the task of taking a loose O-ring and placing the ring into its slot on the respective part. The design will have to be very simplistic to accommodate the wide varieties of mental and physical handicaps. The task is currently performed all by hand, which is meticulous and labor intensive. In order to label each part, they will be defined as the base part, tip part, and stem part, shown in **Figures 4.1.1, 4.1.2 and 4.1.3** respectively.

Figure 4.1.1 Base Part

Figure 4.1.2 Tip Part

Figure 4.1.3 Stem Part

4.2 Benchmarking

When beginning to generate ideas for design, initial thoughts of complex systems such as automatic vibratory feeders and hand presses were mentioned. After doing research on a company by the name of Whitney Systems Inc in Chelmsford, MA [6], we found that these systems, **Figure 4.2.1**, would be too costly, noisy, and may eliminate the actual job of a worker. A more simplistic design was necessary.

Figure 4.2.1 Automatic O-Ring Feeder and Press

Some of our concept ideas were influenced by OTB Designs & Engineering, LLC [5]. In **Figure 4.2.2**, there is an O-ring that is slid into a cavity of a platform. The part is then pressed down by hand to insert the O-ring in the inside of the part. The simplicity and effectiveness of this design has given much insight into the types of concepts we may generate and provides an alternative to automatic feeders and presses.

Figure 4.2.2 OTB Designs & Engineering

4.3 Applicable Patents

Listed below are some of the patents that we felt were applicable to the design process. For each patent, there is a description of how the device works, as well as what was learned from that design.

Patent #1: O-Ring Insertion Tool [7]

Patent number: 4141129
Filing date: Sep 27, 1976
Issue date: Feb 27, 1979
Inventor: Leonard J. Martini

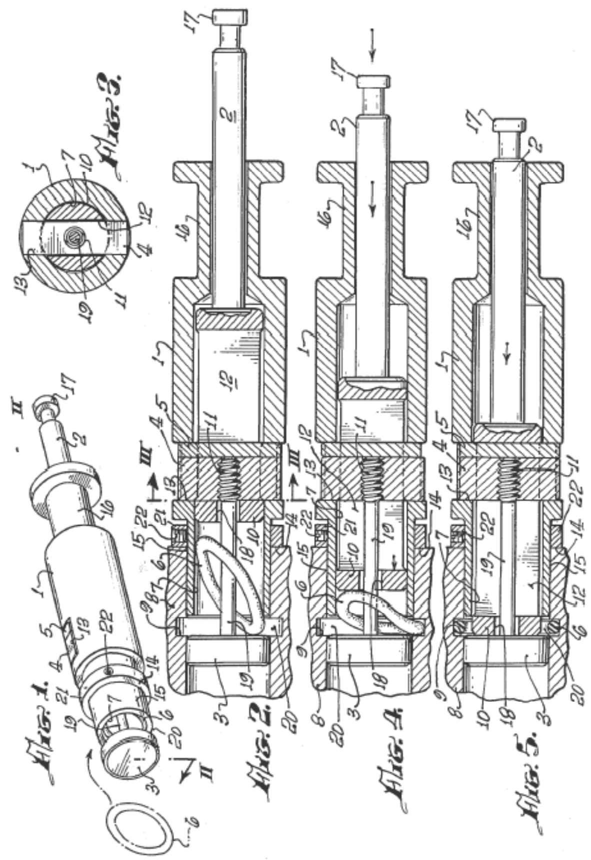

Figure 4.3.1 O-Ring Insertion Tool

This patent is for the installation of O-rings into female seal grooves located internally of a bored cylinder. This device is based off of a medical syringe with some modifications. Figure 1 shows the O-ring (6) being placed within the syringe. In Figure 2, the O-ring is still inside the syringe, and the syringe has been placed within the bored cylinder (8). In Figure 4 the plunger (2) has been depressed and the O-ring is being placed within the desired groove (9). Lastly, in Figure 5, the plunger has been completely depressed, and the O-ring is entirely in the groove and the syringe is ready for removal.

While this device is for internal O-rings and the project being focused on is for external O-rings, our group can learn from this design. The first thing is that it gives another method for using a press. Rather than being stuck on the idea of some sort of arbor press, this syringe provides a simpler and cheaper way to get the same motion desired from an arbor press, without the unnecessary costs and without the overpowering force that an arbor press provides. Another great aspect of this device is the size. If this device could be altered in order to be applied to the QCD Encore than it would be a huge space saver.

Patent #2: Face Seal O-ring Insertion Tool [8]

Patent number: 6012209
Filing date: Jul 8, 1998
Issue date: Jan 11, 2000
Inventor: Merle A. Whetstone

This patent introduces a design made to insert flexible O-rings into a recess. This device is particularly used for installing O-rings into a "half dovetail recess." It is a simple design, which makes the device lightweight and portable. The ram, mounted to a base, consists of a chamfered edge to flex the O-ring, allowing it to pass over the lip of the recess. A spring loaded sleeve is placed over the ram, which also contains a chamfered edge.

For normal operation, an O-ring is first placed within the "O-ring cavity," of the ram. The part is positioned, with the recess inward, adjacent to the chamfered surface of the sleeve. Next, the part is pressed downward to engage the ram, stretching the O-ring. Once the part contacts the top of the ram the chamfer forces the O-ring into the groove, using a constant distributed force. The figure below is a schematic of the proposed tool.

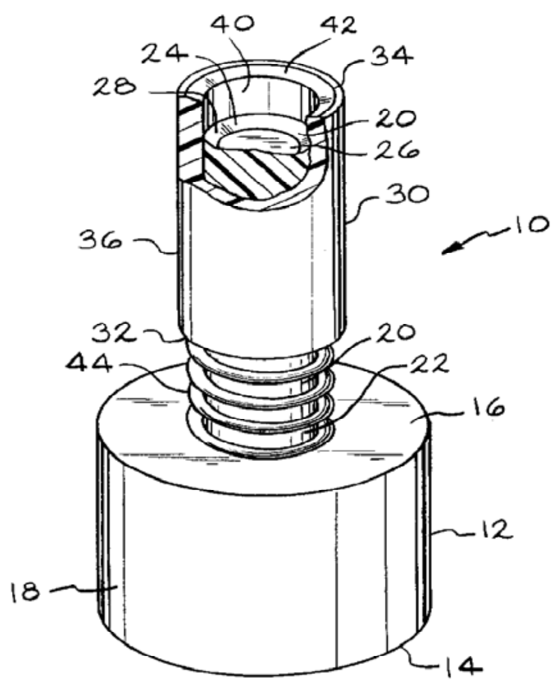

Figure 4.3.2 Face Seal O-Ring Insertion Tool

This tool utilizes physical properties that we are looking for in our design. It is portable, easy to use, and relatively low maintenance. We have also thought of ways to utilize chamfers to stretch the O-rings. Conceptually, this design is like ours minus the movable ram. Rather than a movable ram, to directly install the ram, the O-ring is stationary, while the part is used to apply the force, to insert the O-ring into its seat.

Patent #3: O-Ring Insertion Tool [9]

Patent number: 5050282
Filing date: Aug 27, 1990
Issue date: Sep 24, 1991
Inventor: Frank Zannini

This patent introduces a way of installing flexible O-rings. The device was created to insert O-rings into an inner groove of electrical connectors. It consists only of a shaft and a cylindrical slider, or “contact member,” to install the seal. The shaft end is flared to force the O-ring into its seat, while the tool is removed. The contact member has a section that has been removed. This is done so only one side of the O-ring is in contact with the tool; enabling the O-ring to slide into the groove one side at a time.

Although this device is used for installing internal seals, some of the techniques could be useful. Sliding the O-ring one side at a time, is something we are researching. We have also been discussing the feasibility of a cylindrical cone type shape to slide an O-ring over the part lip, into its seat. This design uses the same concept, giving us good evidence that this idea is feasible.

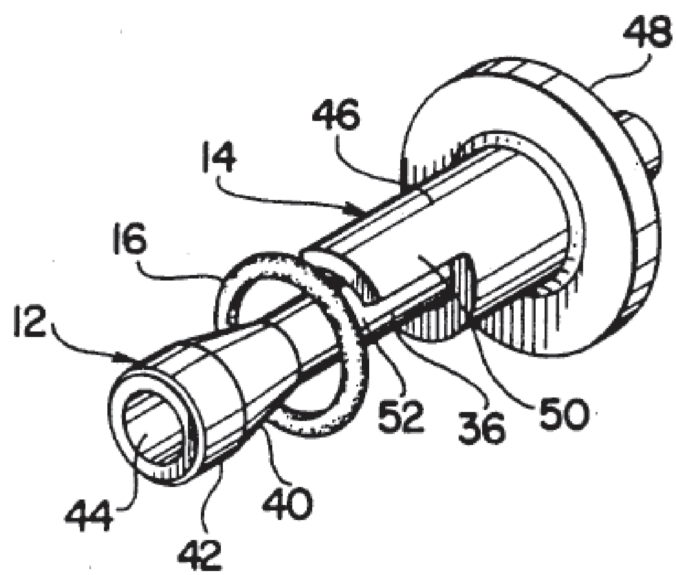

Figure 4.2.3 O-ring insertion tool.

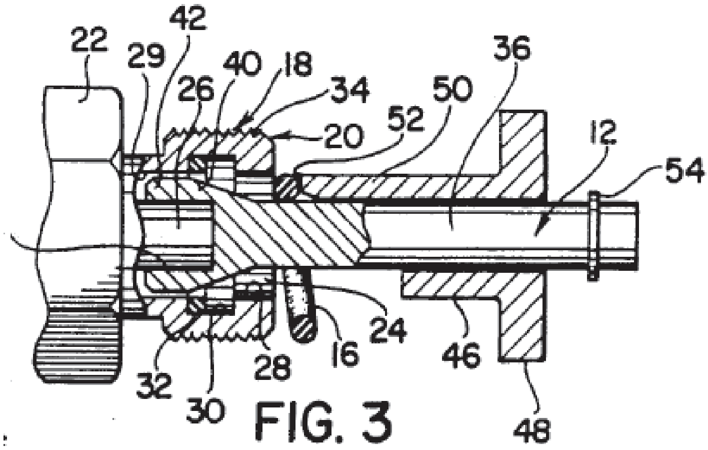

Figure 4.2.4 Tool inserted into electrical connector, and installing a seal.

4.4 Concept Generation

In order to generate several separate and individual concepts, our group began by having each team member come up with two design sketches on their own time. These sketches were based off original ideas that were influenced by previous patents and background research. It was discussed as a team that all design sketches were beneficial and not to be criticized, in order to create a more open and positive brainstorming environment. These sketches were presented during a team meeting allowing all concepts to be drawn on the board and discussed as a team so that all team members understood all of the concepts. Each member asked questions about each concept to develop a general consensus of feasible designs. At this point team members suggested modifications to each design. In addition, some concepts were integrated together to create one overall improved design. The goal of this was to incorporate the best features of each concept into several suitable designs that would yield the best overall feasibility.

Most of the designs incorporated the use of a press mechanism. There was a large variety of designs, ranging from automated feeder systems to manual loading of the O-rings. Some of the designs installed multiple O-rings at once (**Figure 4.4.1**) and some installed one O-ring at a time. The second visit was planned, and some of the designs generated from the brainstorming meeting were presented to SW Resources. Our customer acknowledged our concept generation process and recommended that a final design would be suitable as long as their needs were met.

Another concept which we have considered is shown in **Figure 4.2.2**. This design had no moving parts and the user would only have to roll the O-rings off of the staff onto the part.

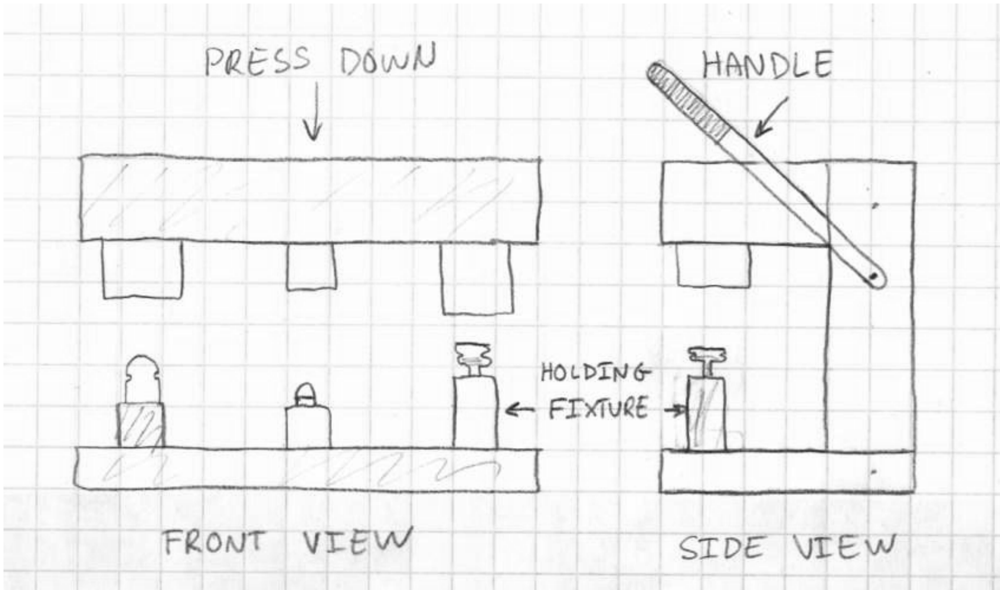

Figure 4.4.1

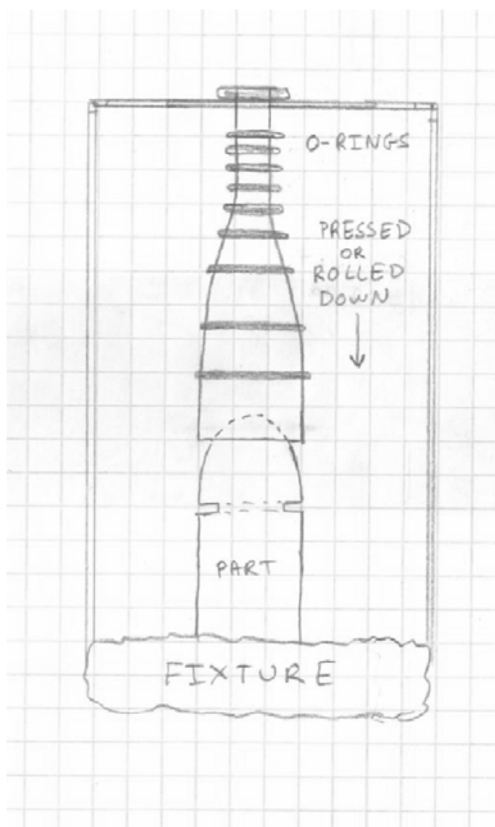

Figure 4.4.2

The concept which initially received the most support from the team due to its simplicity is shown in **Figure 4.4.3**. This design concept is shown as it was originally drafted. We repeatedly modified this design by considering replacing the spring with an air bag contraption, or even just using a mechanical hard-stop.

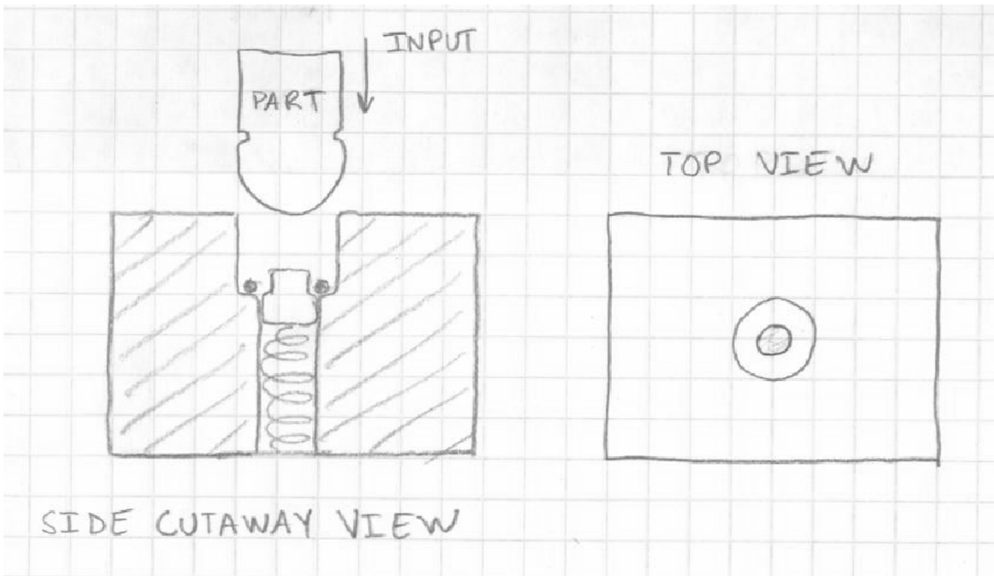

Figure 4.4.3

The process we used for our concept generation can be summarized as a move from fairly complex designs to simpler designs. We incorporated different ideas from each of the initial concepts in order to develop the concepts the team decided were the most feasible to proceed with during the design process.

5.0 Concept Screening and Evaluation

Once we generated several different concepts, we took all of the concepts which our team thought represented the best results of our brainstorming sessions and we analyzed these different designs in an attempt to determine which design was most feasible and would meet the customer requirements and target specifications in a way that was superior to the other concepts.

5.1 Data and Calculations for Feasibility and Effectiveness Analysis

As potential designs continued to be developed and modified during team meetings and on individual's own time, a constant emphasis was placed on design feasibility. With respect to our project, the most simple, cost-efficient, and productive design would be the most feasible. "Simple" is in regard to the operation of the design. A target specification of O-ring application was determined by the group to be achieved in less than 3 steps. "Cost-efficient" is in reference

to the total cost that would be included in materials and manufacturing. “Productive” is in terms of how effective the operator would be while using the design.

With these criteria in mind, designs continued to be worked on and a total of 4 designs were chosen to be potential final concepts. **Figures 5.1.1, 5.1.2, 5.1.3, and 5.1.4** contain the sketches of the four concepts.

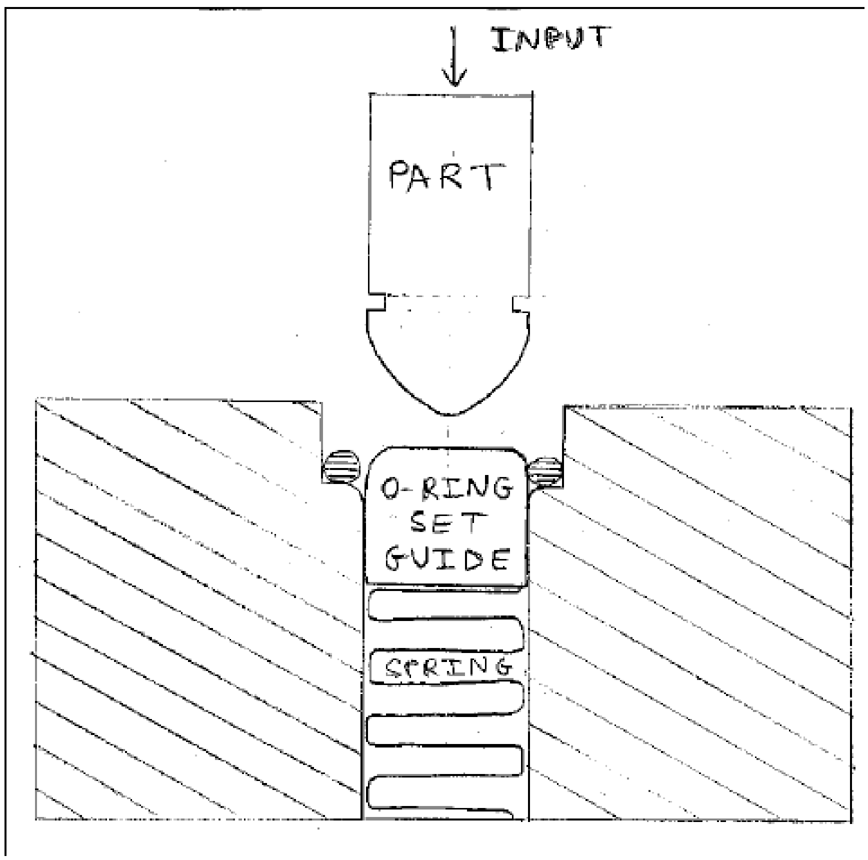

Figure 5.1.1. Design Concept 1

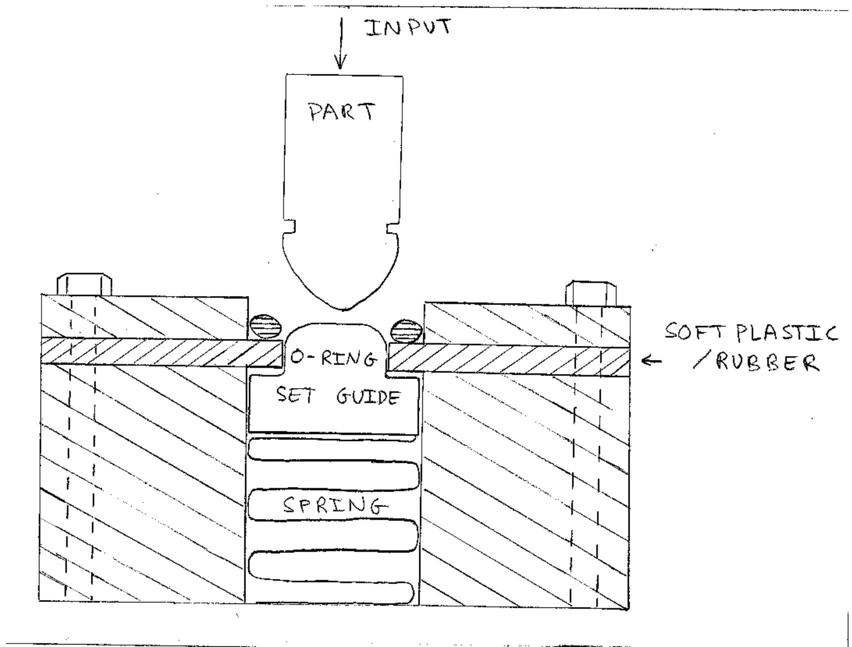

Figure 5.1.2. Design Concept 2

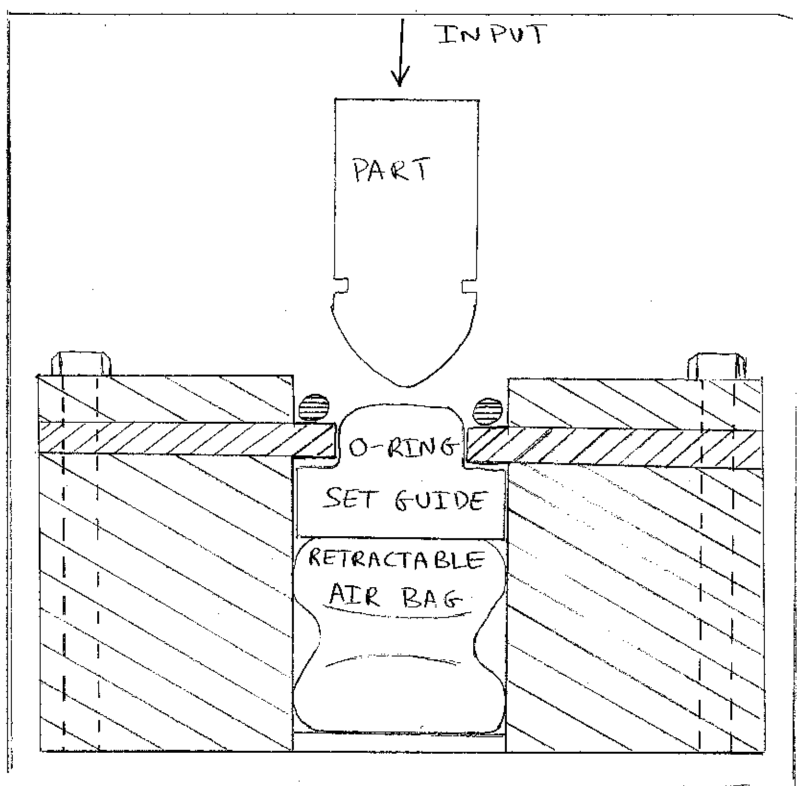

Figure 5.3.1. Design Concept 3

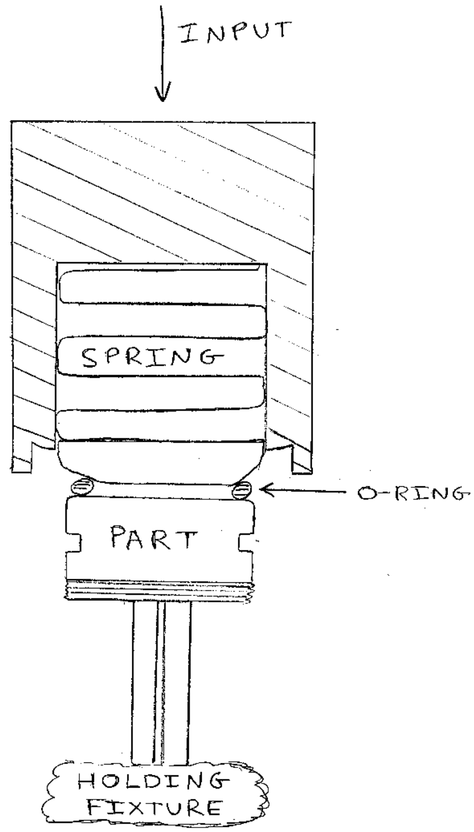

Figure 5.1.4. Design Concept 4

Based on the criteria developed for feasibility and effectiveness, each of the 4 concepts accomplishes each respective goal. With a working budget of about $300, there is sufficient funding available to build 3 separate fixtures, one for each O-ring assembly, based on the volume target specification (< 3 ft^3) and simple geometries of each design. Each concept would meet the productive criteria since each design is projected to allow for an O-ring to be installed in less than 4 seconds. Each design also operates with a force being applied in a linear motion, which installs the O-ring in one step. Placing the O-ring on the guide is another step, totaling 2, which meets the target specification of O-ring installation.

5.2 Concept Screening

Throughout the quarter, our team has made two personal visits to our customer, SW Resources, located in Parkersburg, West Virginia. Other than the personal visits, regular contact has been made with Kellie Conrad (manager) through email and phone calls. After the first visit, our group met for an initial brainstorming session, where each member presented their own initial ideas for installing the 3 O-rings on the QCD Encore. The main factors taken into consideration while brainstorming are listed in **Table 5.2.1**.

Table 5.2.1: Concept Generation Criteria

Safety
Manufacturability
Sanitary
User-Friendly
Maintenance
Cost

5.3 Concept Development, Scoring and Selection

The approach used for developing the best concept for feasibility was by comparing each concept to the criteria established by the team to fulfill the target specifications. These requirements include; safety, manufacturability, sanitary, user-friendly, maintenance, and cost. On a range of 1 to 5, with 1 being the least important and 5 being most important, the team determined the level of importance each one is to our design. This number was multiplied by the *average* level of importance, which was determined by allowing each team member to compare the concepts to each of the design criteria. This consisted of determining the level of importance each concept has on the design criteria by rating them from 1 to 5 as before. By taking the sum of the product of average level of importance and criteria, concept 2 was weighted the largest. **Table 5.3.1** shows this method used.

Once the concepts were compared to the criteria, the next step was to evaluate them on whether or not they meet the target specifications (**Table 5.3.2**). The target specifications are based upon the work area and production levels observed during one of our visits to SW Resources. If any of the concepts exceed the specified target specifications, it will be hard for SW to use, thus may be ruled out.

Table 5.3.1 Design Weighting/Feasibility

Criteria	Concept 1	**Concept 2**	Concept 3	Concept 4
Safety (4)	4(4) = 16.0	**4(4) = 16.0**	4.17(4) = 16.6	3.83(4) = 15.3
Manufacture (3)	3.66(3) = 11.0	**4.30(3) = 13.0**	3.50(3) = 10.5	3(3) = 9.0
Sanitary (5)	3.83(5) = 19.1	**3.66(5) = 18.3**	3.50(5) = 17.5	3.83(5) = 19.1
User Friendly (4)	3.83(4) = 15.3	**4.17(4) = 16.6**	4.33(4) = 17.3	4.0(4) = 16.0
Cost (1)	3.5(1) = 3.5	**3(1) = 3**	3(1) = 3	3(1) = 3
Maintenance (2)	3.17(2) = 6.3	**3.67(2) = 7.30**	3.17(2) = 6.3	3.67(2) = 7.3
Size (1)	4.5(1) = 4.5	**4.5(1) = 4.5**	4.50(1) = 4.5	5(1) = 5.0
Total	75.80	**78.80**	75.80	74.83

Table 5.3.2 Target Specifications

Specifications	Concept 1	Concept 2	Concept 3	Concept 4
Weight < 30 lbs	Y	Y	Y	N
Volume 1.5 ft^3	Y	Y	Y	N
Ratio 3:1	Y	Y	Y	N
3 steps of fewer	Y	Y	Y	Y
Failure Rate	TBD	TBD	TBD	TBD
900 parts per hour	TBD	TBD	TBD	TBD
30-40% production increase	TBD	TBD	TBD	TBD

Criteria Standards:

Safety- Will device be safe for workers? Will any moving parts be dangerous to workers hands?

Manufacture- Does the team have the ability to manufacture the concept? Do we have the resources?

Sanitary- Would it be possible to use cleaning solvents to de-sanitize the device?

User Friendly- Will the device be simple enough for workers with less severe disabilities to operate?

Cost- Which concept would cost less to develop? Could the concepts be developed under $500?

Maintenance- Will the device have low maintenance? If utilizing moveable parts, will they have a low failure rate?

Size- Will device be versatile? Will there be enough room for many of these to be placed on a 8x4ft table? Could the workers fit device in wash sink for sanitary purposes?

6.0 Final Concept Selection

After carefully examining the four concepts, the team agreed that concepts one, two and four are the final candidates. Concepts one and two will be used for installing the O-ring onto the QCD body, and plug. We will be developing a parallel design development for these two concepts because we have decided that we need further data to determine which concept is the better design. By developing these two concepts in parallel, we will be able to test the prototypes and directly compare how well they perform the desired task of applying the O-rings. These concepts are very similar operation, requiring that the employee places the part within a jig. **Figure 6.0.1** shows a diagram of concept one. Notice, that this design is easily manufactured, and very simple to use. It consists of a spring loaded stop to guide the part into the hole. The O-ring will be held in place with an inner edge, on the inside of the hole. This ledge will be made at a diameter slightly smaller than the diameter of the O-ring, forcing the O-ring to slide into its seat.

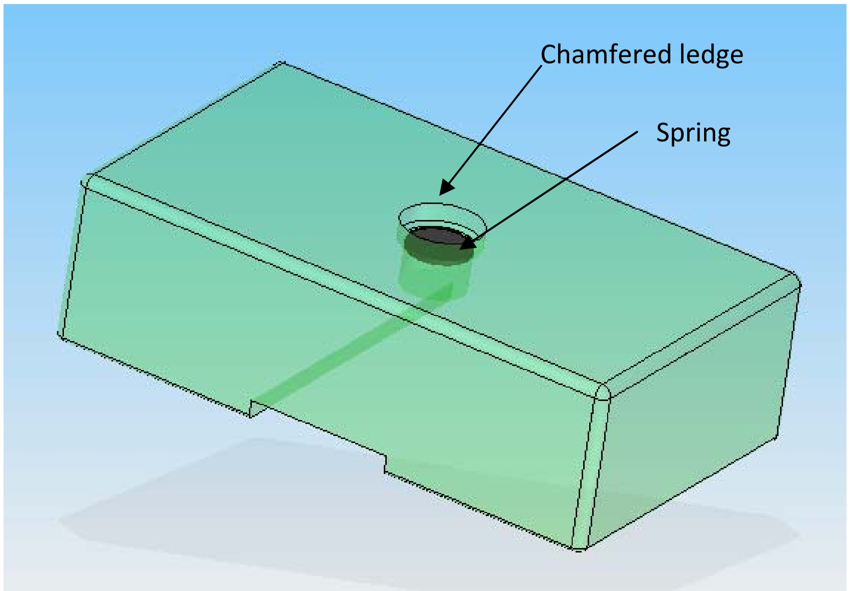

Figure 6.0.1. Concept one uses a spring and cap to guide part.

Concept two is slightly different in the way that the O-ring is held. As in the first concept, a hole will be bored into a plastic base. Rather than machining a ledge, this concept utilizes an elastomer to hold the O-ring, (**Figure 6.0.2**). This material will be placed between the plastic base, and a stainless steel top, held together with four "hand-tighten" screws. A hole will be cut, with a smaller diameter than the O-ring, directly above the hole in the base. This allows for the part to be forced downward, until the O-ring slips into its seat.

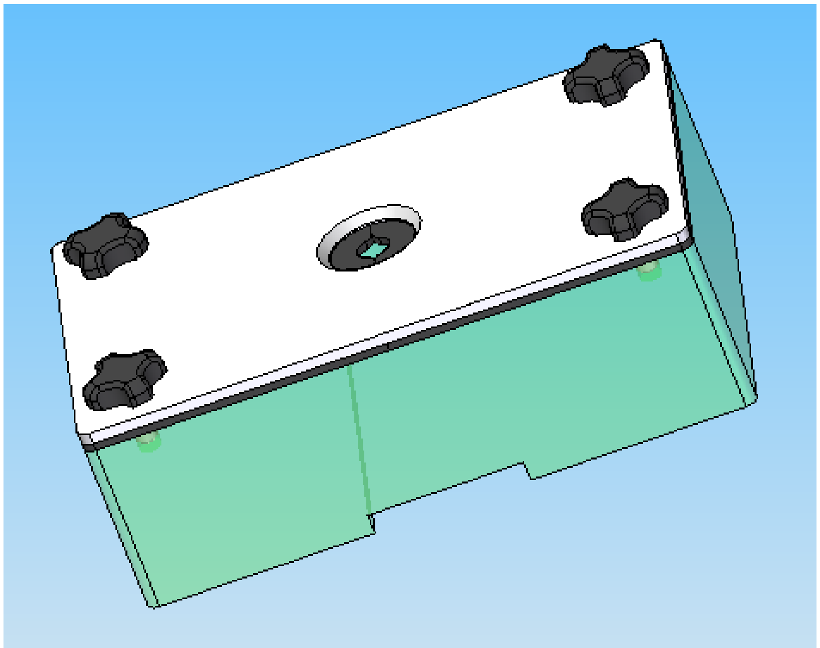

Figure 6.0.2. Concept Two, using rubber to hold O-rings

Concept four was chosen to install the O-ring onto the dispenser shaft. The shaft introduces geometries that will not work with concepts one or two. This concept will use a spring loaded tool head to place the seal onto the part, placed into a specially designed holder. The chamfered head would stretch the O-ring, forcing it to roll downward, over the head into its seat. This design will be slightly more complex because the geometry of the part requires that the O-ring must be initially stretched.

Before manufacturing the prototypes, the concepts will be introduced to SW Resources. Any new ideas will be applied and the concept testing will begin. This is a crucial step in developing the final design, from concepts one and two. Because we do not have enough information yet to determine which of these concepts will yield a better design, mockups of both designs will be manufactured in order to test and compare the differences. From this, a final design will be agreed upon, using the best features of each concept.

6.1 Final Concept Diversification

Prior to any mock-up construction, we identified a potential weakness in all of our design concepts because none of them incorporated a method for feeding the O-rings into the fixture to be installed. To correct for this, we added a metal O-ring feed tray to our fixtures. This tray is shown in **Figures 6.1.1 and 6.1.2**.

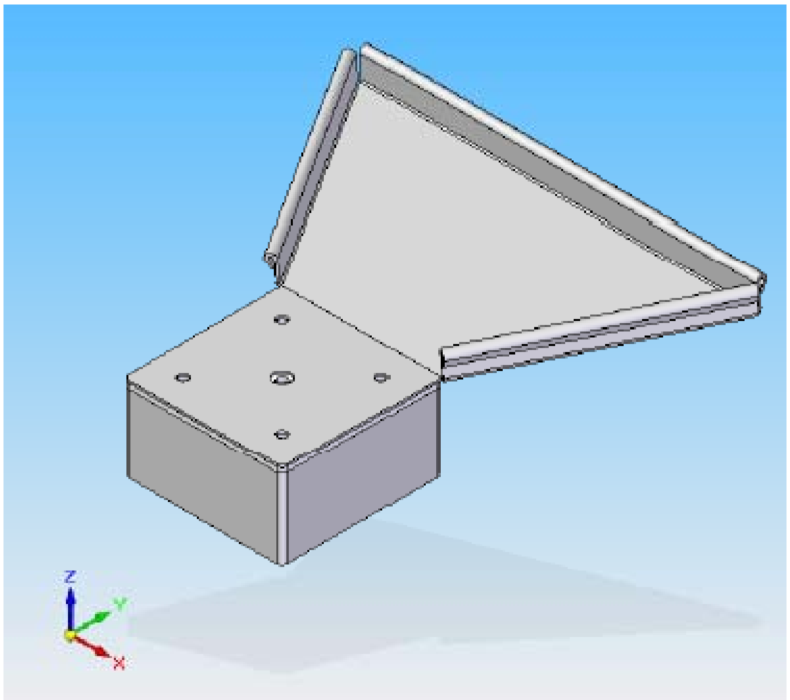

Figure 6.1.1. Concept 1 for O-ring Feed Tray

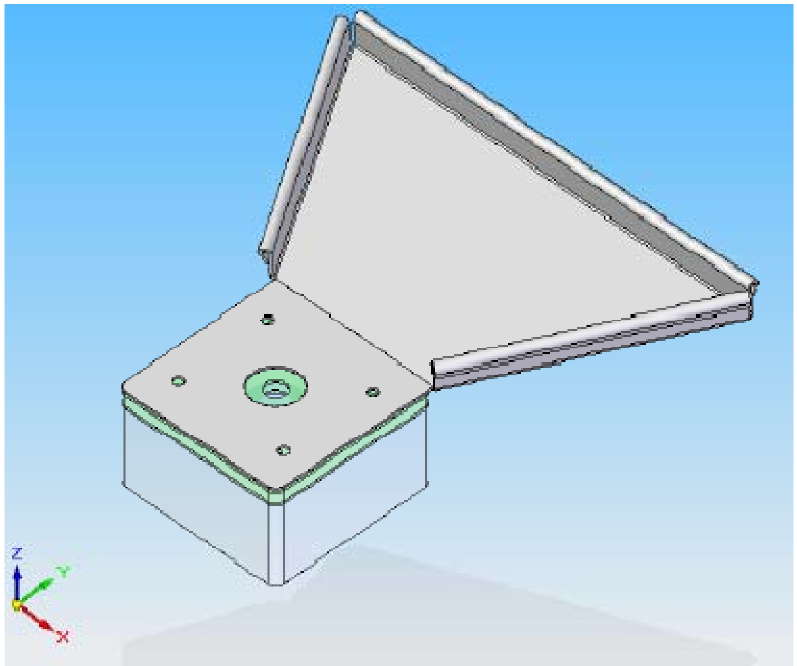

Figure 6.1.2. Concept 2 for Feed Tray

At this point, the team had focused on generating a single design which could be used to install all three of the O-rings. However, after initial mock-up construction and testing, the team determined that the unique geometries of the three parts and the different problems encountered with the installation of the three different O-rings, three separate designs should be explored for the three O-rings. The first concepts for the three distinct designs are shown in **Figures 6.1.3, 6.1.4, and 6.1.5**.

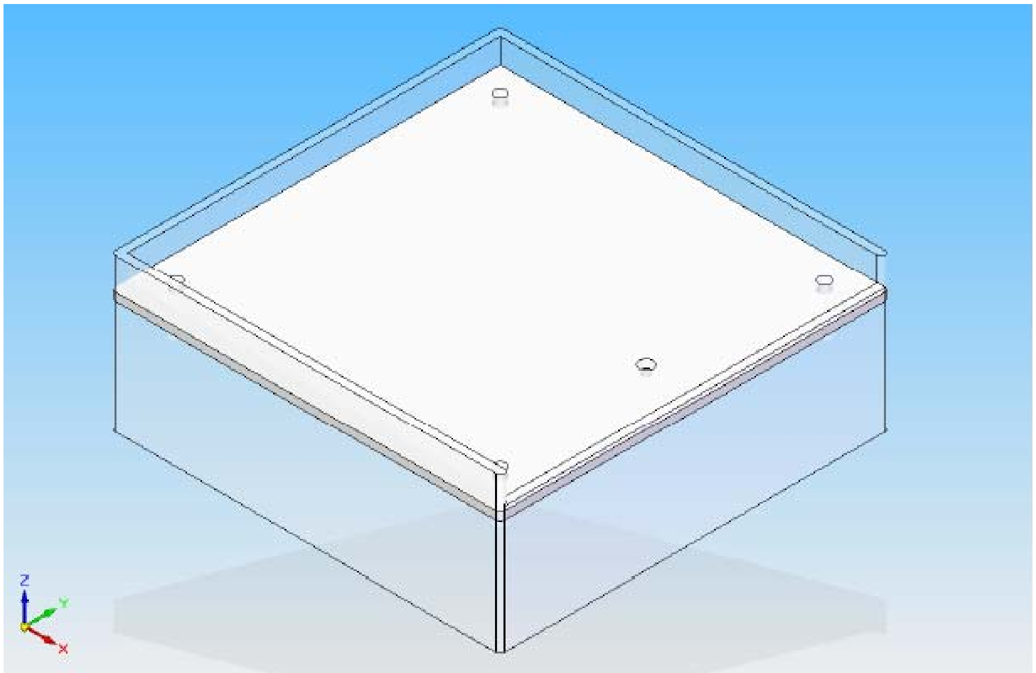

Figure 6.1.3. Design Concept for Small O-ring Fixture

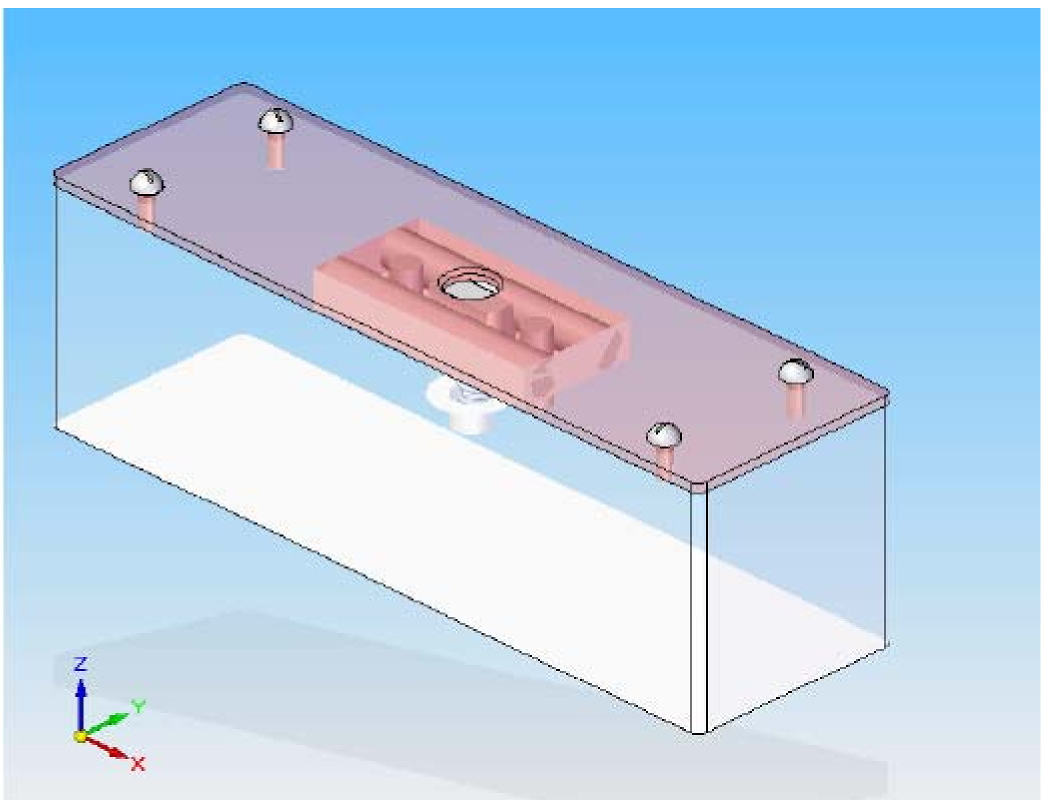

Figure 6.1.4. Design Concept for Medium O-ring Fixture

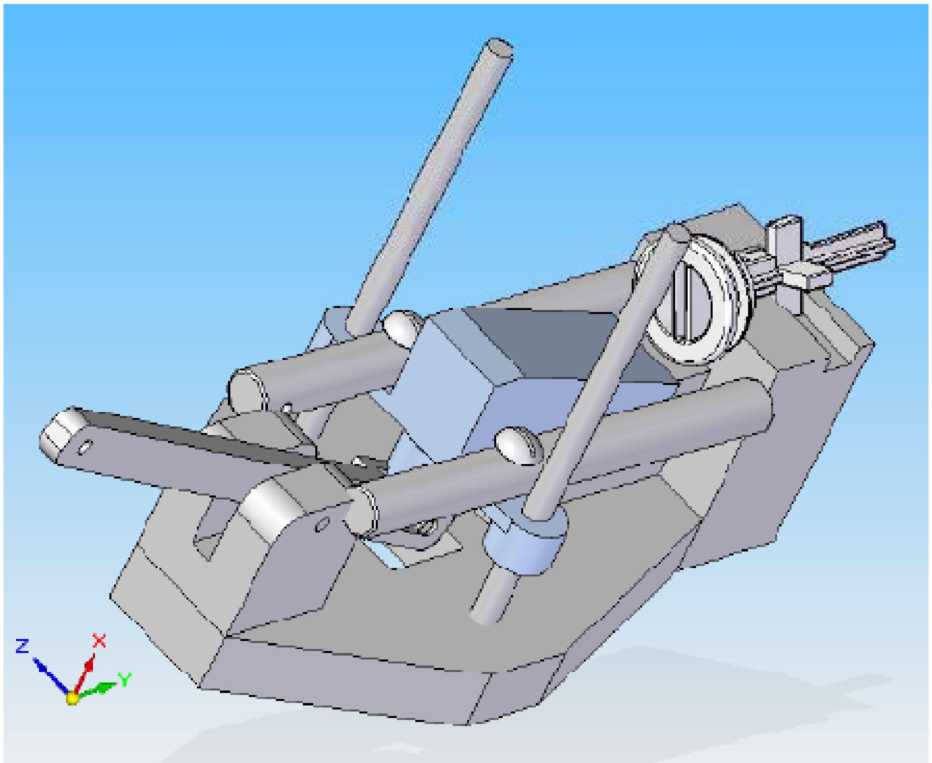

Figure 6.1.5. Design Concept for Large O-ring Fixture

7.0 Prototype Design, Development and Testing

~~Discuss in brief the development of three distinct prototypes, one for each of the o-rings. Add either here or previous section why this route was taken.~~

7.1 Failure Mode and Effects Analysis

In order to develop a robust design, we made use of the Failure Mode and Effect Analysis (FMEA) to identify major potential failure modes and hazards for the systems we were designing and to incorporate features into our designs to minimize the risk of failure or hazards as much as possible. In order to ensure that our design met our specifications, we developed some empirical tests for our designs, focusing particularly on the failure modes which have either a higher risk of occurrence or a greater severity.

FMEA is an important tool for design engineers because it is "an engineering technique used to define, identify, and eliminate known and/or potential failures, problems, errors… from the system, design, process, and/or service before they reach the customer" [14]. The power of this method is that, when used effectively and correctly, it "provide[s] the practitioner with useful information that can reduce the risk (work) load in the system, design, process, and service" [14]. It is extremely useful as a preventive tool.

The method we employed was to rate each failure mode based upon three component factors: the severity of the failure, the likelihood of its occurrence, and the probability of detection. We

obtained numerical estimates of each of these factors by giving each one a rating on a scale of 1 to 10. To determine the potential severity of failure, we had to consider whether the device would perform the desired task reliably and whether the user might be harmed through use. In order to estimate the probability of occurrence, we considered the risk of harm associated with use of the device and what factor of safety should be incorporated into the design. Finally, to determine the probability of detection, we assessed the likelihood that any failure would be discovered by the user prior to the time when failure would occur. **Table 7.1.1** gives the details of the scaling we used in our numerical weightings [15]. We could then obtain an overall estimate for each identified failure mode, a "Risk Priority Number" (RPN) by calculating the product of the severity, occurrence, and detection.

Table 7.1.1. Description of Rating Scale for FMEA

Rating	Potential Severity	Likelihood of Occurrence	Probability of Detecting and Avoiding
1	Device works, no impact on device performance, no danger to user	No chance of occurrence, significant operating experience, low uncertainty	100% chance of detection and avoidance
3	Device works but with poor performance, no danger to user		
5	Device cannot be operated by user, no danger to user	Good information, no operating experience; minimal testing (design based on analysis only)	50% chance of detection and avoidance
7	Device works, some detrimental impact on performance, some danger to user		
10	Device cannot be operated, very serious danger to user	Very poor information about loads or operating conditions, wild guesses in analysis, no testing	0% chance of detection and avoidance

We identified seven specific failure modes for our design: 1) incomplete installation of O-ring, 2) O-ring fracture, 3) fatigue failure in the rubber sheet, 4) corrosive wear of the fixture, 5) harm to user due to sharp edges, 6) bending in metal O-ring feed tray, and 7) stripping of threads in plastic base. We then obtained the (RPN) by computing the product of the numerical rating for each of the three factors. Those failure modes with the highest RPN would receive particular attention for corrective actions or testing. **Table 7.1.2** summarizes the results of our FMEA analysis; the actual FMEA worksheets which were used to obtain these results are included in **Appendix C**.

Table 7.1.2. Summary of Initial FMEA Results

#	Failure Mode	Severity (S)	Probability of Occurrence (O)	Probability of Detection (D)	Risk Priority Number (RPN)=S*O*D
1	O-ring not installed	7	6	9	**378**
2	Fracture of O-ring	6	2	7	**84**
3	Fatigue in rubber	8	3	4	**96**
4	Corrosion due to cleaning	7	2	2	**28**
5	Sharp Edges	9	3	1	**27**
6	Bending in o-ring feed tray	7	7	2	**98**
7	Stripping of threads	8	3	6	**144**
8	Fracture if dropped	10	7	1	**70**

From the results presented in **Table 7.1.2**, we determined that the failure modes which needed specific attention during the design process and prototype construction and testing were incomplete O-ring installation, stripping of threads, bending in O-ring feed tray, and fatigue failure in rubber components. Because we had determined that the best course was to develop three separate devices (each one focusing on the installation of a different O-ring), our response to the FMEA results differed depending on the device.

For all of our devices, we decided to eliminate the metal O-ring feed-tray; thus, the probability of occurrence for bending in the feed tray drops to 0%. To eliminate any problems associated with stripping of threads, we determined to eliminate any threaded holes in any plastic materials. Instead, we decided to use threaded metal inserts for any fasteners which would attach plastic parts together in the devices. After these actions were taken, we revised our FMEA and the new results are given in **Table 7.1.3**.

Table 7.3.1. Revised FMEA Results Compared to Initial FMEA Assessment

#	Failure Mode	Initial RPN	Revised RPN
1	O-ring not installed	378	90
2	Fracture of O-ring	84	42
3	Fatigue in rubber	96	27
4	Corrosion due to cleaning	28	20
5	Sharp Edges	27	9
6	Bending in o-ring feed tray	98	0
7	Stripping of threads	144	0
8	Fracture if dropped	70	35

We determined that the revised RPN numbers were satisfactory. However, throughout the manufacturing process of the initial prototype, we focused on adjusting our designs to improve the actual installation of the o-rings. Since the revised RPN for unsuccessful O-ring installation was the highest, we determined that we should focus efforts on improving the design to allow for easy and consistent operation and installation. After finite element analysis (described in section 7.3) we determined that the fracture of the o-ring, fracture of the fixture, and fatigue in the rubber were not likely to occur in our design. More details on the tests and our conclusions are given in

Section 7.3. By rounding all corners and edges, we eliminated any safety hazards sharp edges would cause, and we selected materials for our prototype that were specified by the manufacturer to be corrosion resistant. By eliminating any need for threaded holes in the plastic, we determined that stripping of the threads was no longer a potential failure in our designs.

7.2 Prototype Material Selection

The most important requirement for our materials is that they would be FDA compliant. For this reason, we decided that, for most of our materials, we would use a plastic with good wear characteristics and one which would not be susceptible to corrosive wear due to repeated cleaning. We selected high density polyethylene (HDPE) as the primary material for our fixtures. The rubber material we initially incorporated into our designs was Nitrile aka Buna-N rubber (stretch limit of 300%). However, we determined that two of our prototypes would not use a rubber material in the design, so only the small O-ring fixture includes this material.

As is discussed in Section 7.5.1, this rubber was replaced with Natural Latex Rubber (stretch limit of 810%) after we tested our first generation prototypes. For all of the materials we used brass inserts with screws as the fasteners and connectors. For the reasons discusses in Section 7.1, we decided not to drill any threaded holes in the plastic bases because of concerns over thread stripping.

For O-ring trays in the medium and large O-ring fixtures, we used Lexan instead of metal because Lexan provided us with excellent strength characteristics and yet was very low weight. We also used stainless steel rods in both of these designs.

7.3 Design Analysis

For our preliminary design analysis, we employed finite element analysis as a method to explore different design issues and potential failures in a non-destructive way prior to actually manufacturing our prototypes. Using the results of this method, we could analyze our system's stability and robustness without incurring extensive costs associated with repeatedly testing real prototypes which were subjected to destructive testing. We tested each of the three designs independently using FEA. Some of the test simulations we performed were similar for each of the three designs but they all had to be performed because each design differed from the others.

We also performed FEA on O-ring fracture, which is applicable to all three designs. The following discussion relates to this analysis. It was important for the elastic bands in the fixture to be able to withstand the input force of the part into the fixture. The required input force to push the part through the bars was found to be 60 Newtons using a digital force gauge.

The elastic band was modeled in SolidEdge and cut into ¼ of the original size to benefit from symmetry (**Figure 7.3.1**).

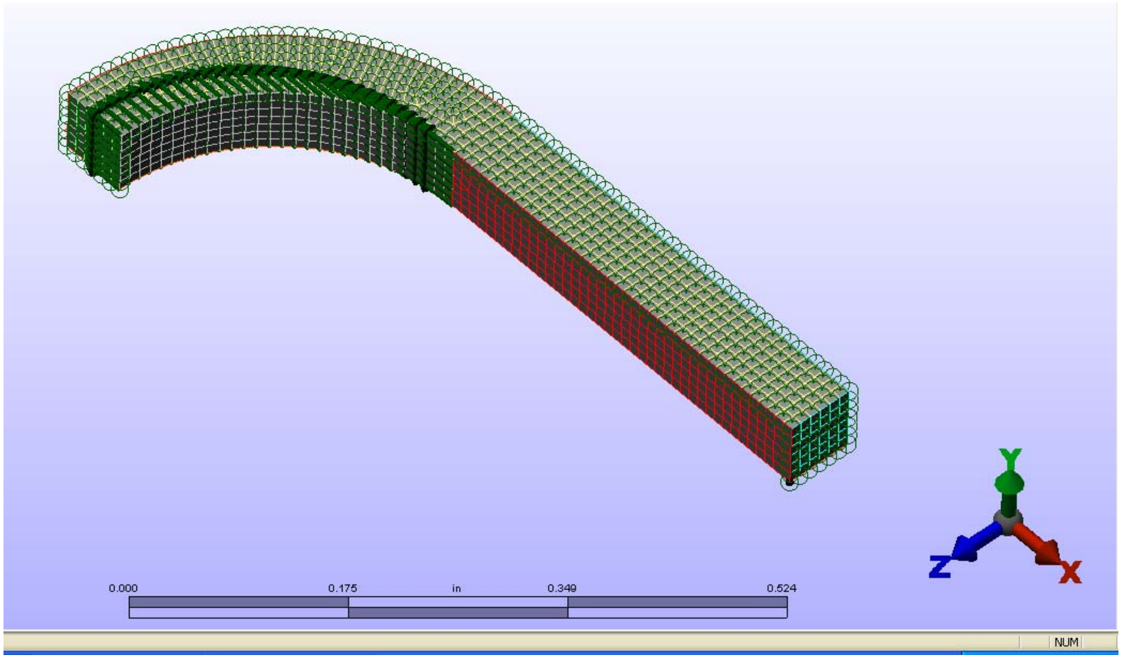

Figure 7.3.1. Elastic Band FEA Mesh

The following was done to simulate the tensile force applied to the elastic band:

- 6.7 lbf was applied to the curved surface in the negative X-direction
- Cut surfaces were fixed in their respective directions due to the effect of symmetry
- Material selection: Rubber
- Element Definition: Mooney-Rivlin

A nonlinear analysis was run three times, decreasing in mesh size each time, to find the von Mises stress in the elastic band. The results were compared the material being used in the fixture:

Table 7.3.1. Material Properties of O-Ring

Material	Buna-N
Description	70D (Durometer scale)
Tensile Yield Strength	2,150 psi
Elongation %	400

Table 7.3.2. Elastic Band Stress Results

Test #	Mesh Size (in.)	Max Strain (in/in)	Max Stress (psi)	Displacement (in)
1	0.05	0.278	464.02	0.668
2	0.025	0.400	433.5	0.168
3	0.020	0.417	421.3	0.156

After 3 tests, the maximum stress value converged to within 2.8%. A stress of 421.3 psi is well below the yield strength (2,150 psi) of the Buna-N rubber and verifies that the elastic band will not fail while pushing the part through the bars during the assembly.

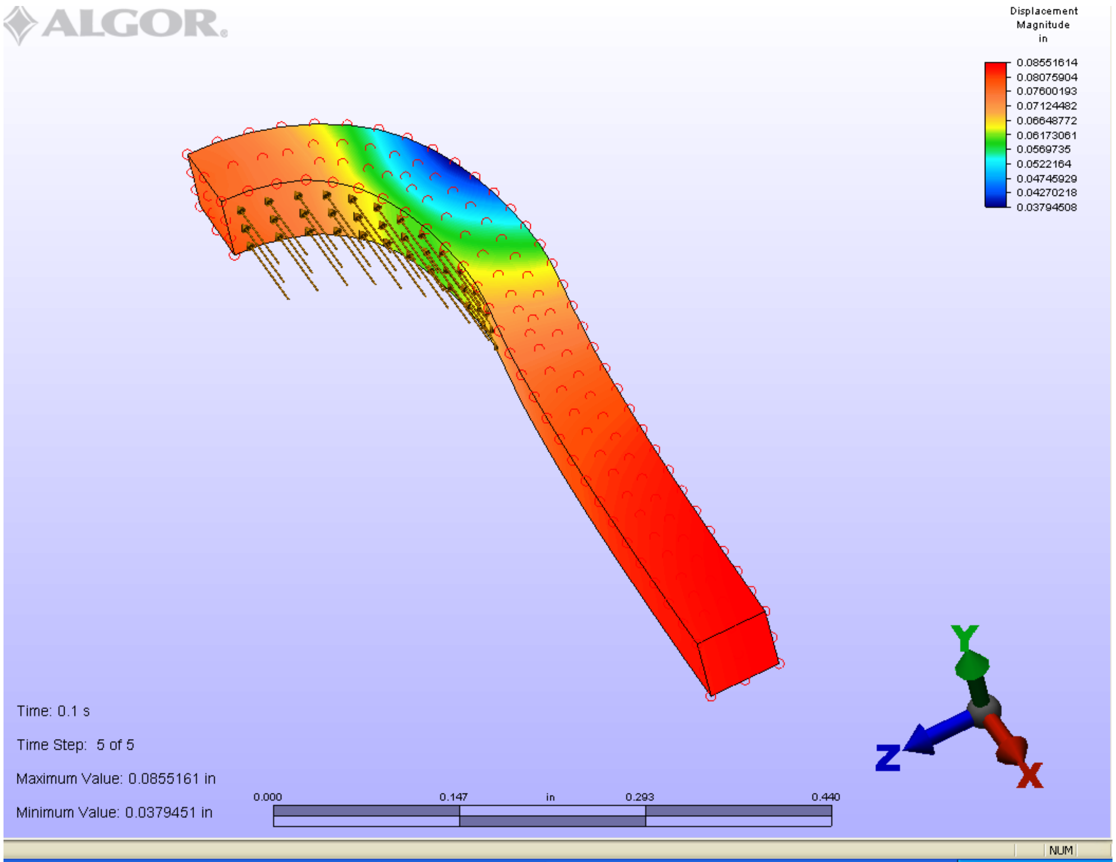

Figure 7.3.2. Elastic Band: Displacement

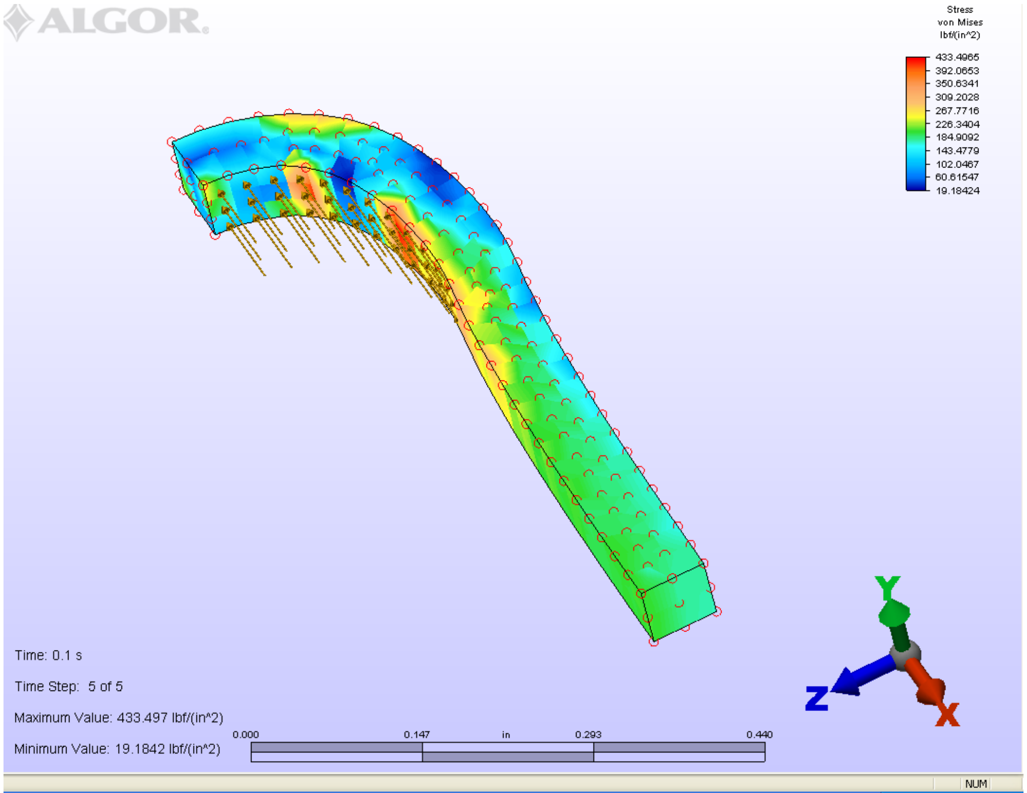

Figure 7.3.3. Elastic Band: von Mises Stress

7.3.1 FEA for Large O-ring Fixture

The first failure scenario we investigated specific to the large O-ring fixture was the dislodging or torquing of the platform inside of base. This platform moves in the fixture when the user places the stem part onto the platform and presses down to install the large O-ring. The geometry of this part is shown in **Figure 7.3.1.1**.

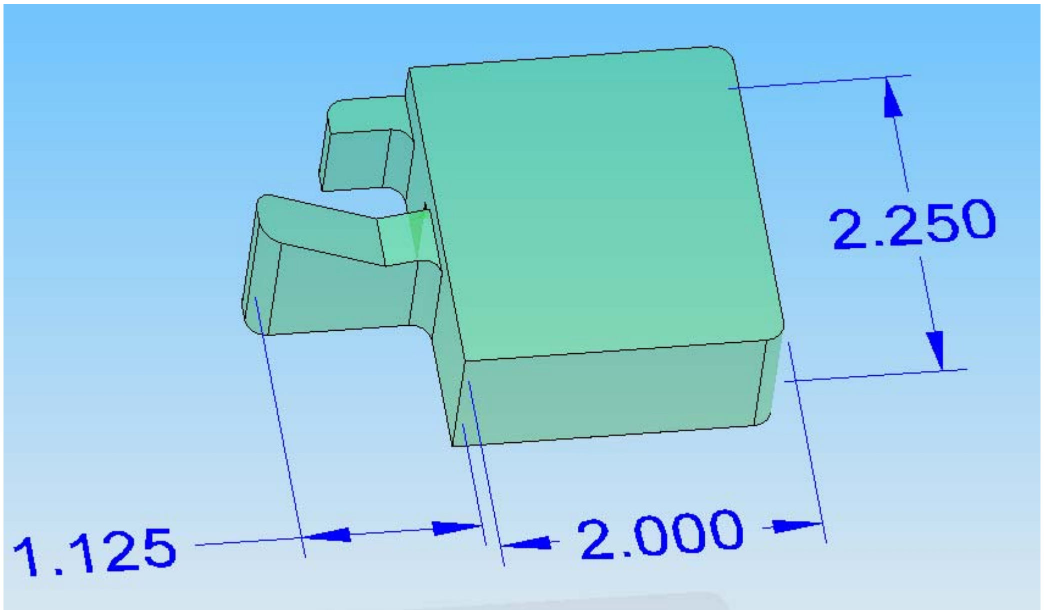

Figure 7.3.1.1. Geometry of Platform

The materials of which this part is made of is HDPE(injection molded), which has an average tensile yield strength of 3773 psi. For this analysis, an edge force was applied in the Y-direction with a force of 20 lbs at the beginning of the radius on the flange. The three edges with circles were constrained using a pinned constraint. The bottom face of the part was fixed in translation in the Z-direction. In the event of the part being torqued, the pinned edges would be the only places where contact was made.

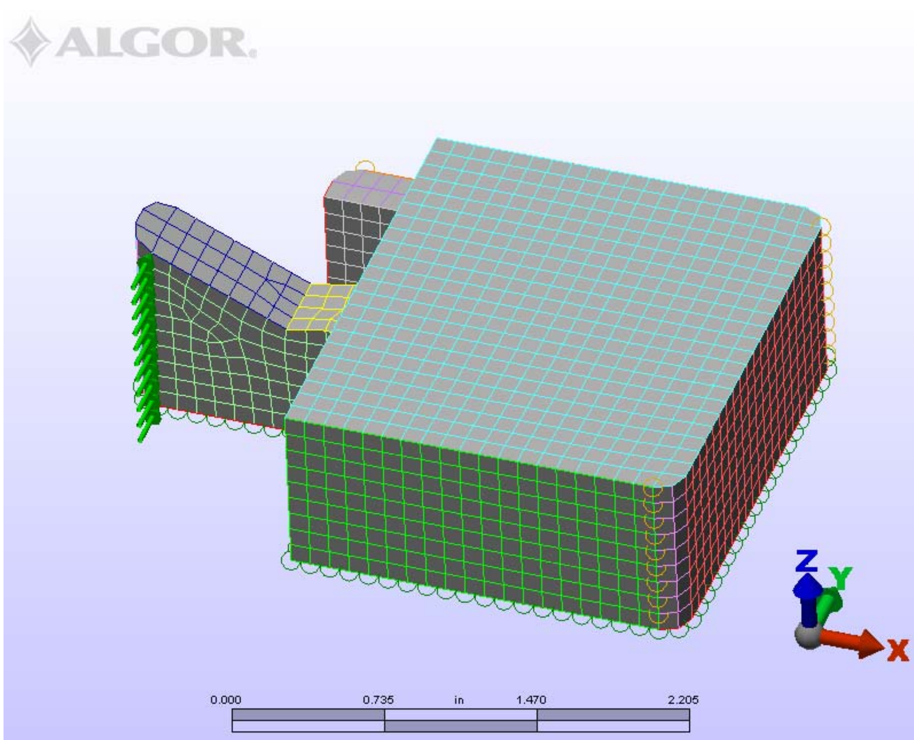

Figure 7.3.1.2. Loads and Constraints

The results of this analysis are summarized in **Table 7.3.1.1**.

Table 7.3.1.1. Platform Stress Analysis

Mesh Size (in)	Nodes	Aspect Ratio	Max Displacement (in)	Max Stress (psi)
0.2	1010	3.78	0.028	1185
0.1	5961	2.87	0.030	1317
0.05	41923	4.21	0.032	1400

Convergence was met as the stress did not increase much compared to the number of nodes. The displacement is above normal because the HDPE material is somewhat flexible itself. However the deflection of the material will be limited due to the orientation in the base. The percent difference of the stresses is 5.9%, which is acceptable. The yield strength is 3773 psi. Thus, the part will not fail with a maximum stress of 1400 psi.

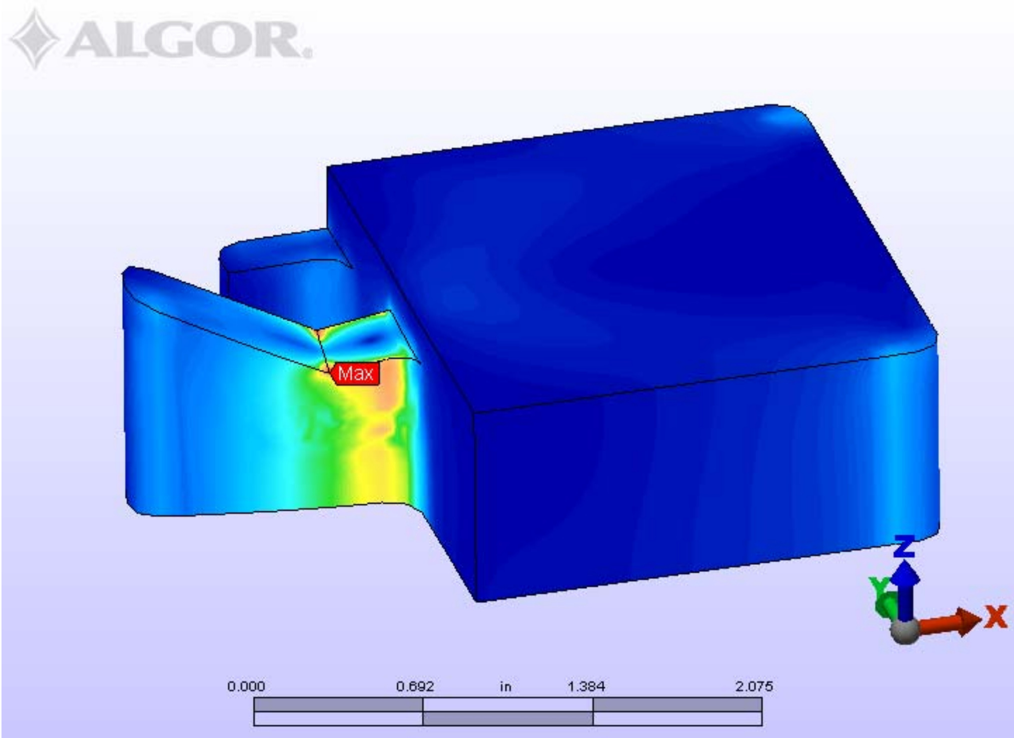

Figure 7.3.1.3. Maximum Stress

The second failure mode we analyzed for the large O-ring design was bending in the O-ring feed tray. Initially, all three designs incorporated this feature which would allow users to place O-rings on the tray and then slide the O-rings onto the fixture for installation. However, in the final design, only the large O-ring fixture incorporated this feature of the tray as distinct from the actual fixture used for installation. Were the tray to fracture or bend, the fixture's usefulness would be greatly reduced because the users would then need to place each O-ring individually on the fixture for installation instead of placing a large quantity of O-rings onto a tray and then moving each one into place.

The tray was analyzed with a 24 pound force on the outer edge.   This force was calculated using the impulse momentum equations. Constrained on the face where it meets the part, (fixed). Plate elements were used, with mid-plane meshes. This analysis is the worst case loading scenario for the tray. The loads and constraints applied to the tray are shown in **Figure 7.3.1.4**.

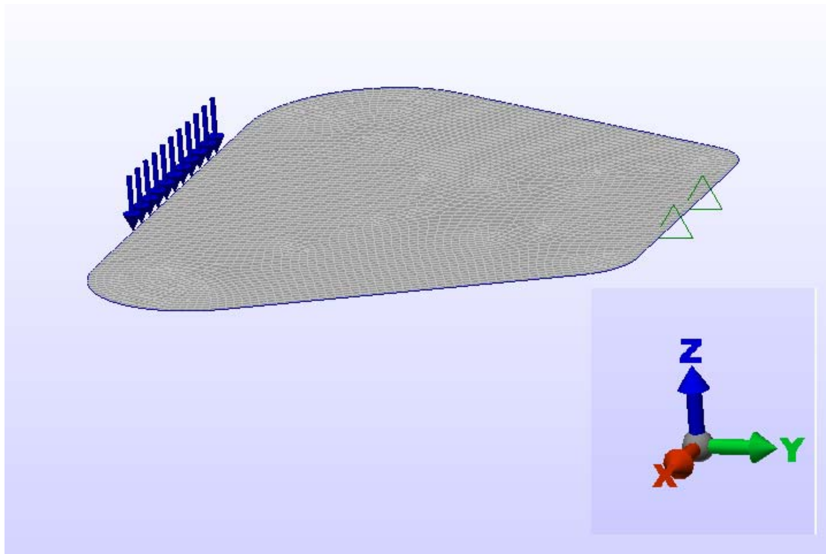

Figure 7.3.1.4. Loads and Constraints

Table 7.3.1.2 summarizes the results of our analysis.

Table 7.3.1.2. Force on Tray Results

Mesh Size (in.)	Stress (VM) psi	Strain (VM)	Aspect Ratio	Nodes
.5	1522.4	.003	1.243	321
.25	2333.6	.0046	1.26	777
.2	2356.7	.005	1.26	1222
.125	2370.8	.0052	1.33	3072
.1	2378.17	.0057	1.27	4566

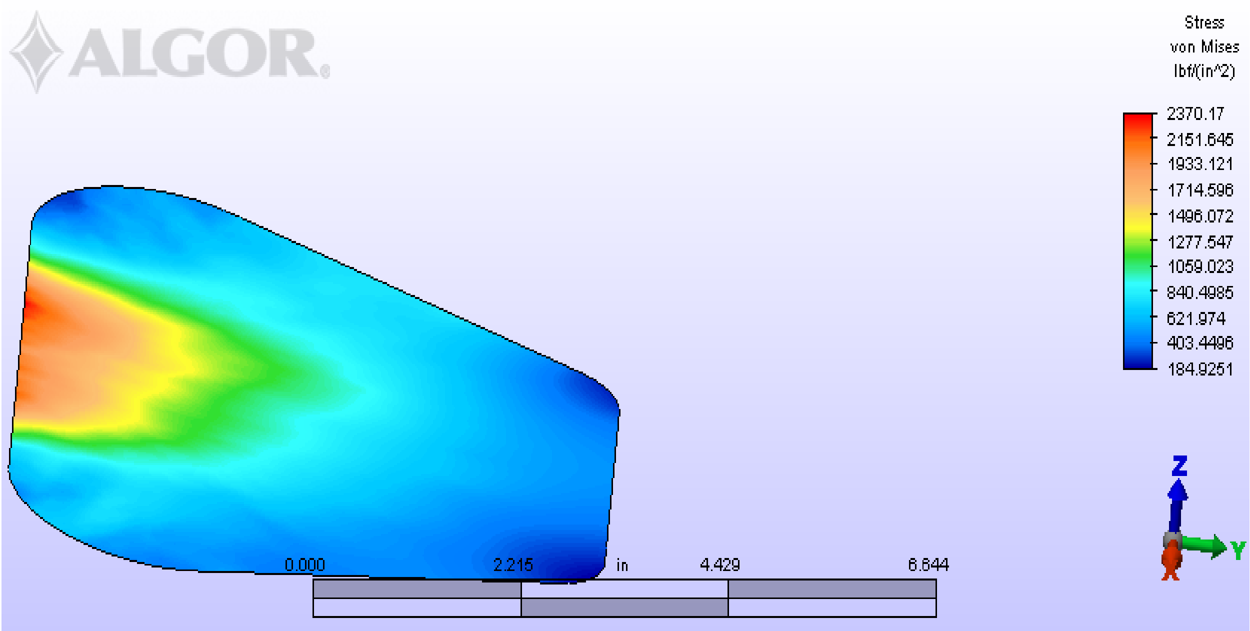

Figure 7.3.1.5. Maximum Stress

Convergence was achieved to a final value of 2378.15 psi. This was checked by comparing the number of nodes to the increase in stress. Lexan has a yield strength of 8300psi, (matweb). From this I conclude that the tray should be able to survive a 4 foot fall, with an impact on the rear edge.
Since this prototype contained more parts, as well as a large Lexan tray, drop analysis was necessary in developing a durable device. The yield strength of Lexan was found to be 8300 psi. Also we added an HDPE rail around the perimeter of the tray, not included in FEA that will further help absorb an impact. The figures below show the loading of the tray, and the point of maximum stress.

To find the impact force, conservation of energy, and the impulse momentum equations were used. The force of impact was found to be 24.5 pounds-mass.

Once this force was found, it was used in FEA, of the tray, to determine whether the tray will withstand a four foot fall. Setting the input force to be 30 pounds, we found the maximum stress converged to a value of approximately 206 psi.

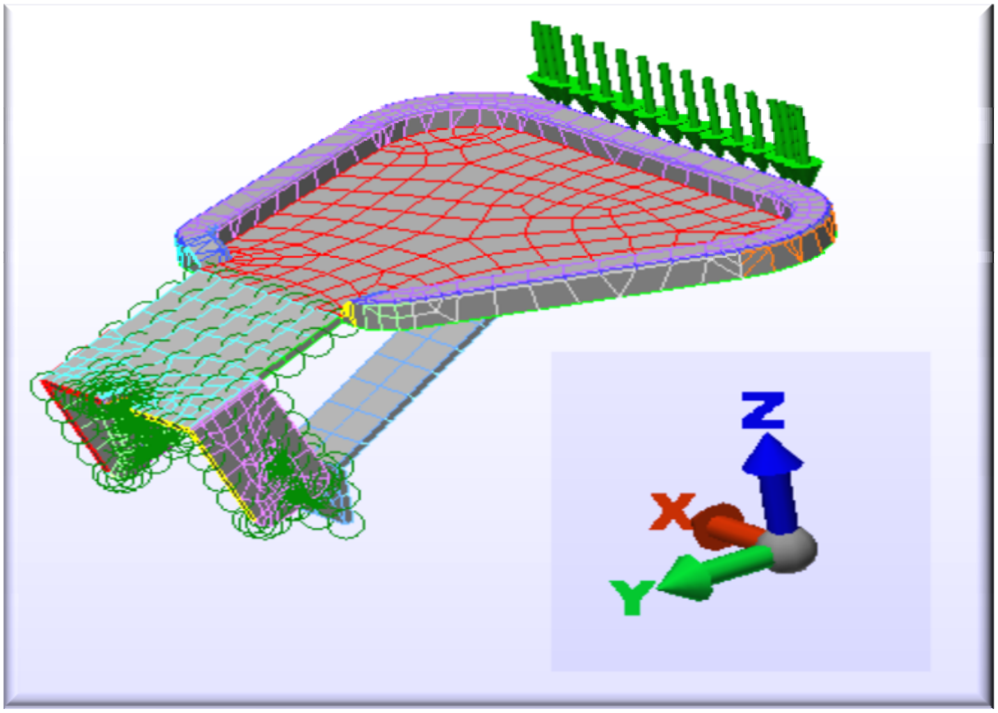

Figure 7.3.1.6. FEA Setup for Bending in Feed Tray of Large O-ring Fixture

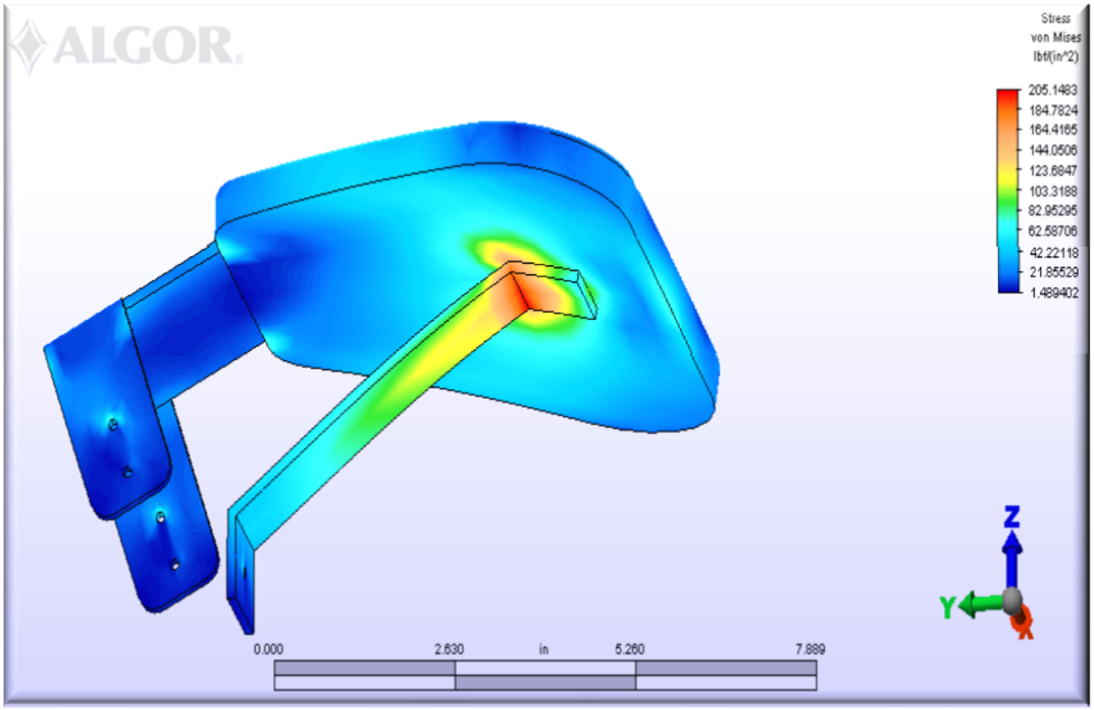

Figure 7.3.1.7. FEA Stress Concentration Result for Large O-Ring Fixture

7.3.2 FEA for Medium O-ring Fixture

For the drop test, we used static stress with linear material models. The element definition was von Mises with Isotropic Hardening and the material selected was HDPE Injection Molded. The properties as follows:

Table 7.3.2.1. Material Property for HDPE Base

Modulus of Elasticity	118,000 psi
Poisson's Ratio	0.37
Yield Strength	3000 psi
Shear Modulus of Elasticity	43,066 psi

Table 7.3.2.2. HDPE Base Stress Results

Test #	Mesh Size (in.)	Max Stress (psi)	Displacement (in)
1	0.5	664.81	0.0035
2 (local Refine)	0.0125	640.39	0.0025
3(local Refine)	0.0625	635.17	0.0023

By applying the Impulse Momentum Theory equation, the average impact force applied to the (bottom) corner of the base from a free fall of 4 ft was 29.91 lbf. This load was applied to one of the bottom corner nodes of the base (Figure 7). The vector select option was used by selecting the direction to the opposite (top) corner of the base. We assumed that the highest stress would occur if the base landed so that a straight line could be drawn from the corner that hits the ground

to the opposite (top) corner of the base. The base was constrained in the positive x, z, and negative y-directions. The opposite (top) corner of the base was pinned so that the blocks impact angle would remain constant.

Symmetry could have been used on this part since we are only interested in one particular area, a corner. The element mesh size was started off at 1 inch. This was decreased by ¼ of an inch for each run until a mesh size of 0.5 inches was reached. With a mesh size of 0.5 inches, the maximum von Mises stress was approximately 665 psi and the maximum displacement was 0.0035 inches (Figures 8 & 9). The total number of nodes was 1034 and 3,102 degrees of freedom (DOF). From here, a test for convergence was done by applying a local refinement with effective radius of 1 inch to the node of maximum stress. The mesh size of the effective radius was decreased by ¼ inch increments until the maximum von Mises and displacement had leveled out. This occurs at a final mesh size of 1/16 of an inch. A maximum von Mises stress was about 635 psi and a maximum displacement of 0.0023 inches.

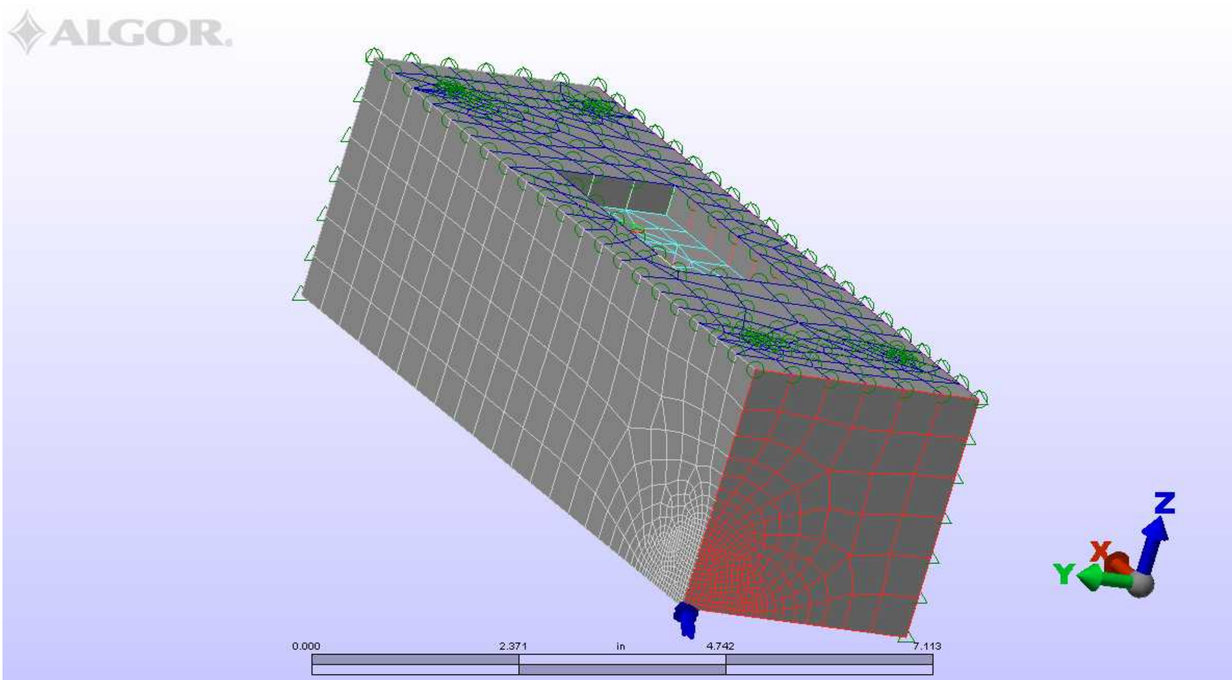

Figure 1.3.2.1. Mesh and Constraints

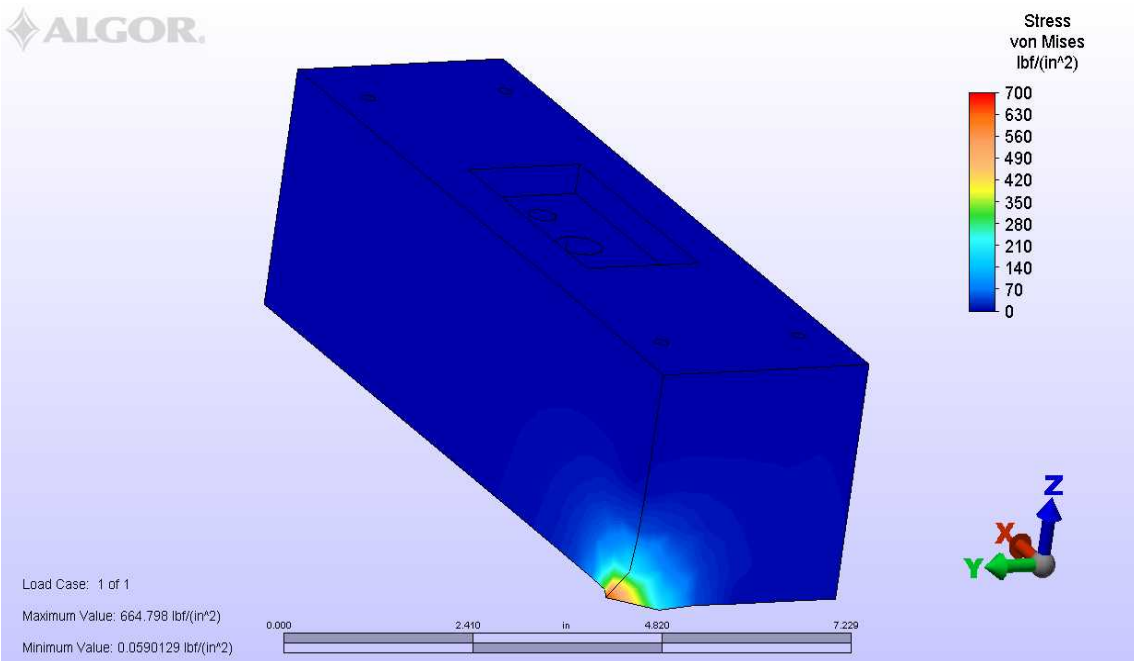

Figure 7.3.2.2. von Mises Stress

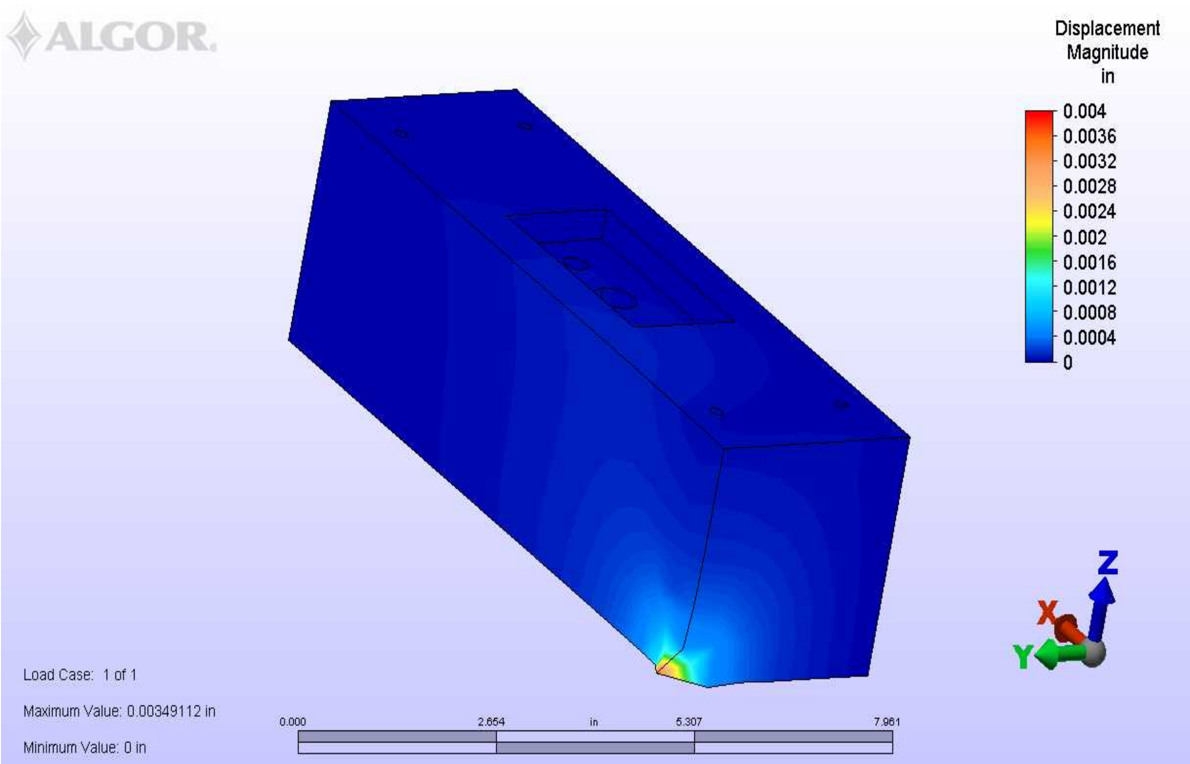

Figure 7.3.2.3. Displacement

Due to size and short drop distance, the maximum stress is not all that important to us. What is important is the maximum deflection. We wanted to be sure that small deformation would occur if this was dropped. Assuming worst case scenario, that is, if impact occurs where the surface area is smallest i.e. the edge corners, deflection would be maximum. From the FEA analysis, a maximum deflection of 0.0035 inches isn't much of a concern and normal operation will continue.

7.3.3 FEA for Small O-ring Fixture

There were two failure modes for the small O-ring fixture that we investigated using finite element analysis. The first scenario was a "drop test," a simulation of the fixture being dropped from its normal height on a table during operation and hitting the floor. As with the other two fixtures, we were concerned that if the user accidentally dropped the fixture, the fixture may catastrophically fail, rendering the fixture completely unusable. If our design were susceptible to this failure, the cost and risk involved in operation could render this device unusable to our customer. The second failure mode investigated for this fixture was material fatigue failure in the rubber insert. Because the rubber insert layer plays a critical role in the design, facilitating the installation of the O-ring with a relatively small input force, if this layer were to fail, the fixture would be temporarily unusable. However, as we discussed in Section 7.1, we designed the fixture so that this rubber insert layer could be easily replaced were the rubber layer to wear out. However, our design, to be feasible, must be robust enough to minimize the number of times the rubber layer must be replaced. Therefore, we wanted to ensure that the rubber layer would last about one year, or one full production cycle for our customer.

For the "drop test," the part to be tested is the base for the small o-ring fixture, simluating a fall from table height (approximately 4 feet high) to the floor. In order to test this, the part has been cut down to a 1.5" x 1.5" x 1" cube for faster meshing. Although convergence was not reached to the level desired, the part could no longer be meshed due to such a small mesh size. Given in **Table 7.3.3.1** are the results of the three different meshes.

Table 7.3.3.1. Mesh Results

Mesh Size (in)	Refinement Point Size (in)	Nodes	DOFs	Elements	Aspect Ratio
.1	.04	4950	14322	6378	6.992
.1	.02	11483	33921	20421	7.197
.1	.01	26640	79920	65383	5.675

The loading and constraints can be seen in **Figure 7.3.3.1**. The mesh tested is .1" for an element side with 32 refinement points along the stress concentrations. The refinement points have an effective radius of .1 inches with varying mesh sizes.

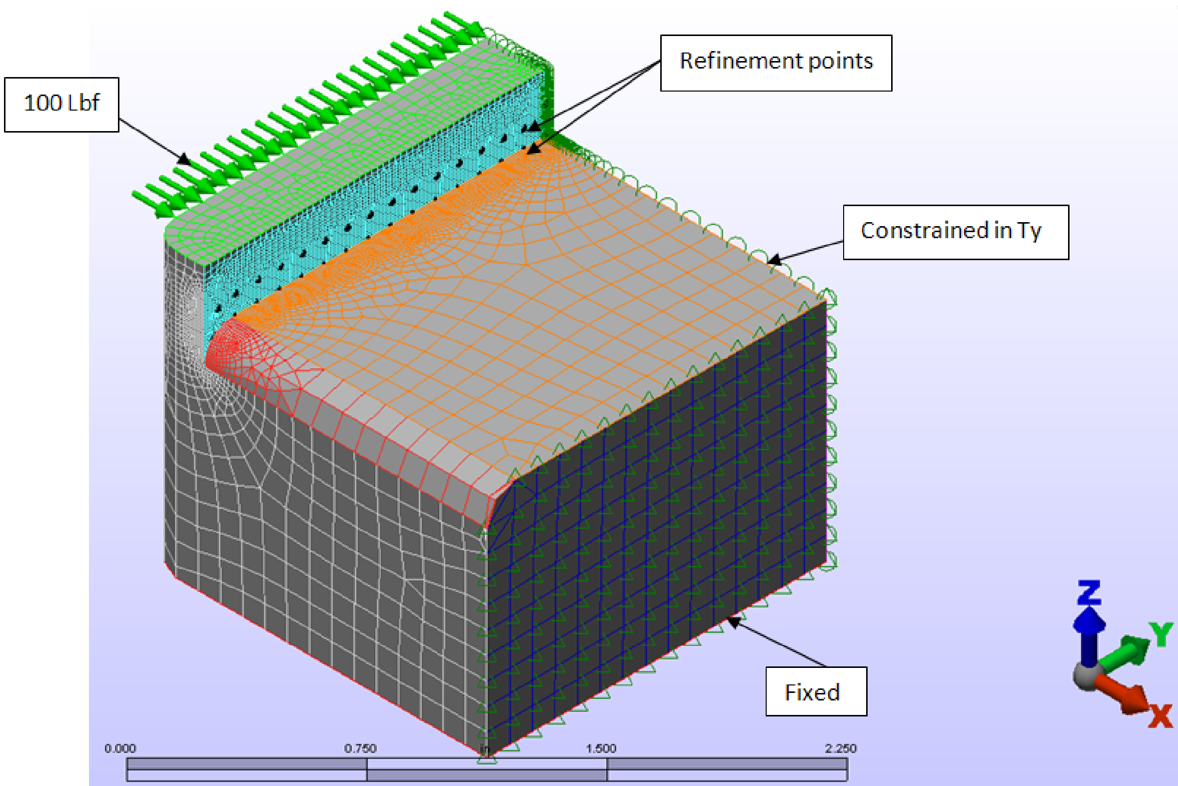

Figure 7.3.3.1. Loads and Constraints

The reason for choosing these loads is to simulate a drop test. By using the impulse momentum theory, it was determined that for a height of 4 feet that the equivalent static load would be 99.4 lbf, so 100 lbf was used. The assumptions made were a time impact of .05 seconds, and a weight of 10 lbs for the fixture.

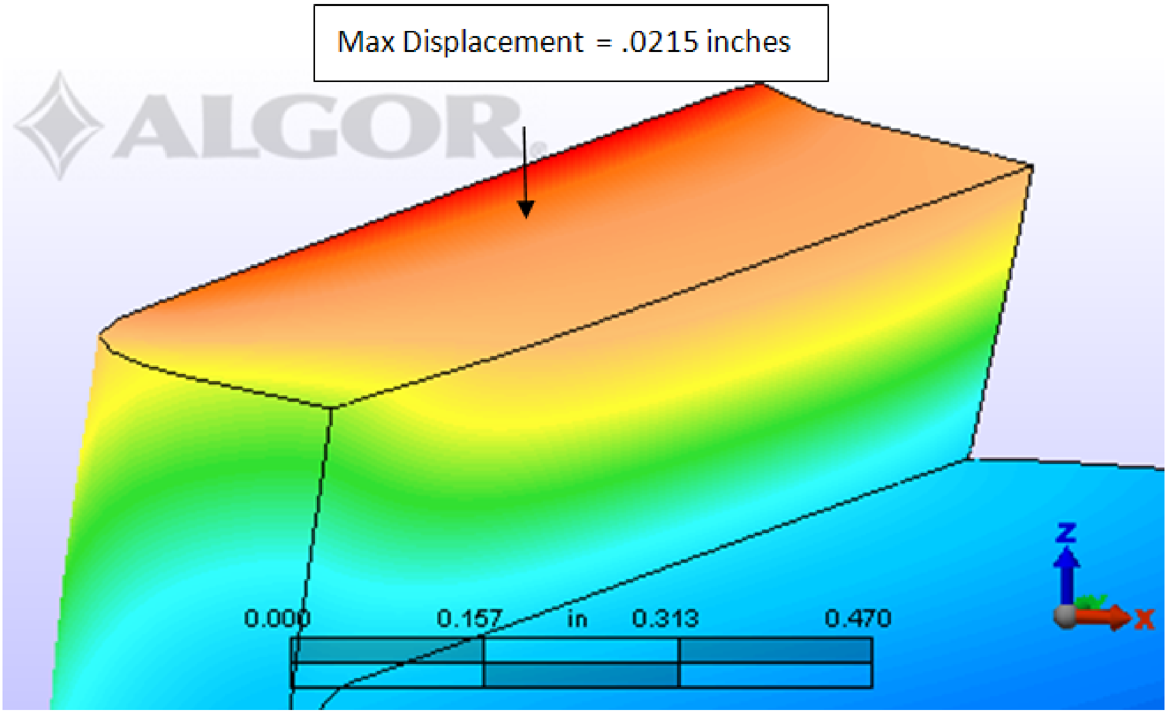

Figure 7.3.3.2. Max Displacement

As seen here in **Figure 7.3.3.2**, the max displacement for the finest mesh gave a displacement of 0.0215 inches. The model shows the displacement times 500%. This deflection is acceptable for the fixture because it will not cause significant failure to the part. The wall that is deflecting is used to keep o-rings from falling off the sides, and the only effect the displacement has is that the part is not as visually appealing.

Given in **Table 7.3.3.2** are the overall results for the three meshes, followed by Figure 6 with the stress concentrations.

Table 7.3.3.2. FEA Results

Refinement Point Size (in)	Max Von Mises Stress (psi)	Max Deflection (in)	Convergence with Respect to Previous Mesh
.04	2119	.0205	N/A
.02	3168	.0213	33.1%
.01	3590	.0215	11.8%

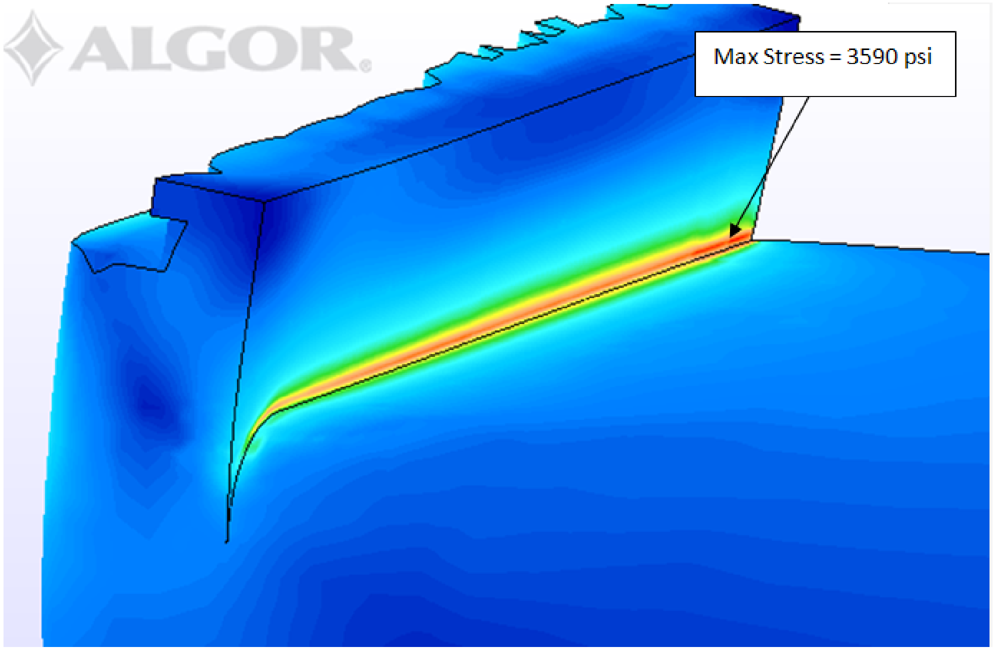

Figure 7.3.3.3. Von Mises Stress Concentrations

The biggest concern here is that the stresses didn't converge quite as much as desired, but the mesh wouldn't run for smaller element sizes. This is cause for concern because the MATWEB yield stress for the part (HDPE) is listed as 580-4600 psi and McMaster Carr gave us a value of around 3500 psi. What this means is that this part will deform plastically at the wall if it hits the ground at the correct orientation. Since the Ultimate tensile strength is 5000-6000 psi, the part will not break. The fact that the part will yield is not an issue for two reasons. The first is that this is a worst case scenario if the part is dropped and lands a certain way. The second is that if the wall were to yield or break it has no significant impact on the worker installing the o-ring. It simply just becomes a minor eye sore. OK

The second failure mode we investigated for the small O-ring fixture using FEA was material failure due to fatigue in the rubber insert layer. As the user presses the small pop nozzle part into the hole of the rubber sheet, the o-ring (which initially rests on the rubber sheet) will expand and roll onto the part. During this installation process, the rubber layer will deform and deflect downwards. Because of its elastic nature, the rubber sheet will return to its initial state. As the rubber sheet is subject to this alternating loading, it could potentially fail due to fatigue.

We have estimated that over the period of one year, this device will be used for 1.5 million cycles. Since our customer needs this device for one year, we will design our fixture to have a life of 1.5 million cycles. According to one S-N curve we have obtained for rubber, for a lifetime of 2 million cycles, the maximum stress is 2.2 MPa, which is 319.1 psi. Thus, if the maximum stress in the rubber layer does not exceed this maximum stress value, we can conclude that we have achieved our desired design specification

According to experimental testing (see Section 7.5 for further details), we have determined that the input force required to press the small tip part into the rubber layer is 5 lbf. With this input force, the o-ring is installed. In our FEA, however, we used a 10 lbf since the user may actually

exert a larger force than is required for installation. Initially, we applied the principle of symmetry to analyze the entire fixture to see how the fixture would respond to this input force on the pop nozzle part.

Because the fixture rests freely upon a table, the base of the fixture was constrained in the z-direction. A pin support was placed on one of the corners of the bottom face. The plane of symmetry was constrained in the y-direction. A picture of this model is shown in the figure on the top of the next page. Since we used only half of the model, the applied force was half of the expected force, i.e., the applied force was 5 lbf.

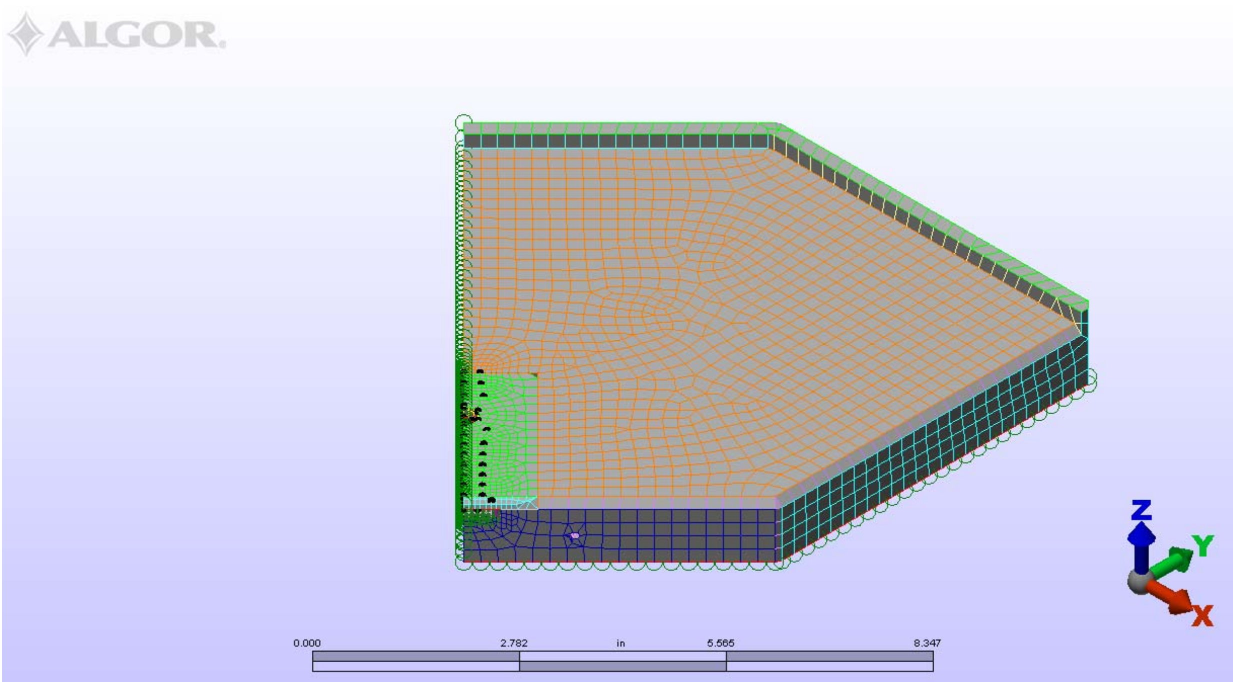

Figure 7.3.3.4. Model of Fixture Using Symmetry

When this mesh was run, the results indicated that stress concentrations existed only in the rubber layer and not in the top plastic cover or in the plastic base. This model was further refined by using only a small block surrounding the hole in the rubber sheet. The bottom face was constrained in the z-direction and the cut planes were constrained in the x and y-directions. Again, the FEA results indicated that stress concentrations existed only in the rubber layer and did not extend to any other parts as shown in the figure on the next page.

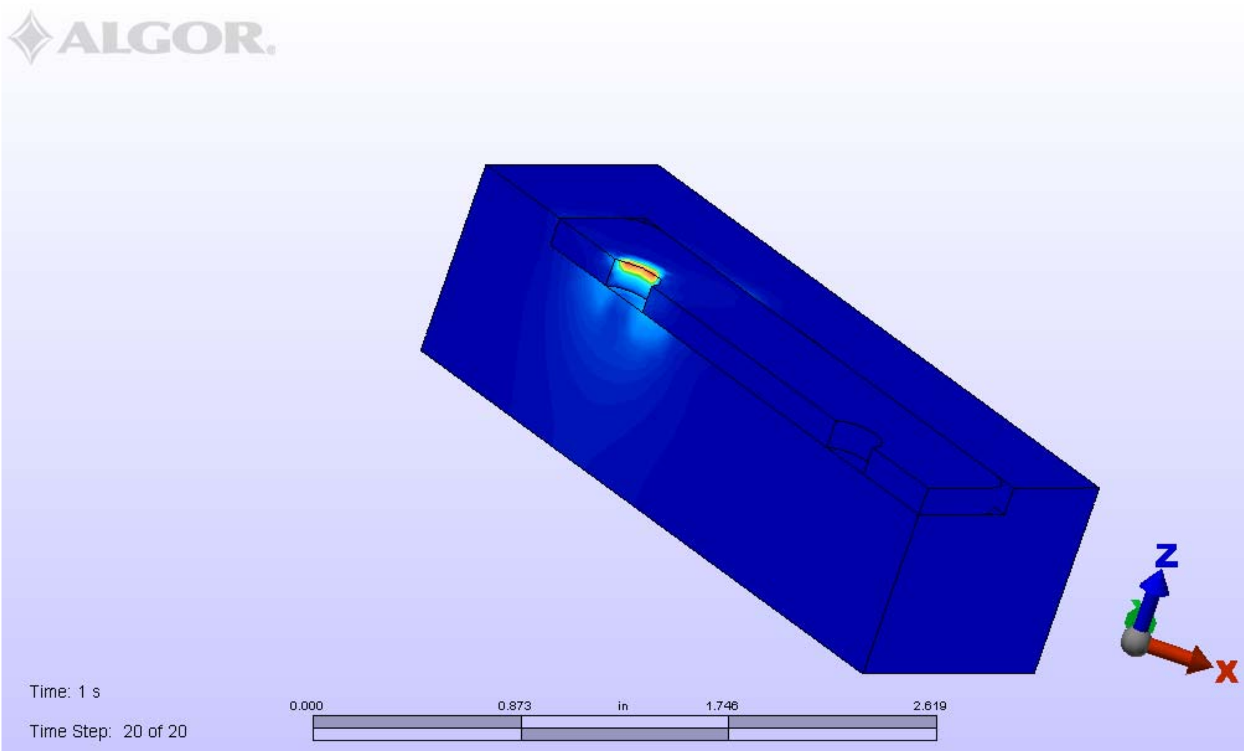

Figure 7.3.3.5. Stress Results for "Block" Assembly of Small O-ring Fixture

Because there were technical problems with successfully getting this model to mesh correctly, and because stresses were located only in the rubber layer, the final FEA looked at only the rubber sheet. For this analysis, we used a 10 lbf surface load in the negative z-direction. For the applied load, we used the maximum value for the alternating load (the load alternates between 0 and 10 lbs). Because the rubber layer rests upon the base of the fixture, the rubber sheet was constrained in the z-direction. The left and right sides were constrained in the y-direction, and the front and back faces were constrained in the x-direction as shown in the following figure. Refinement points were placed along the top outer edge of the hole in the rubber.

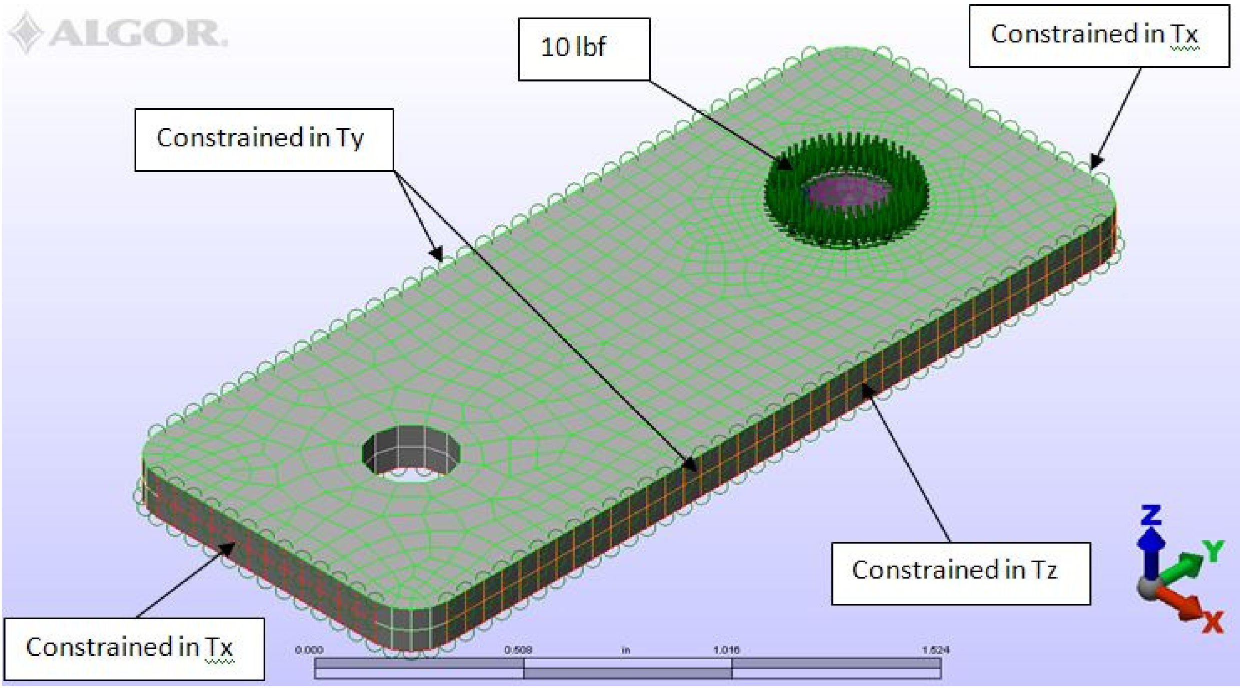

Figure 7.3.3.6. FEA Model of Rubber Sheet With Loading and Constraints

The following table summarizes the FEA results for this rubber sheet.

Table 7.3.3.3. Mesh Results for Rubber Sheet FEA

Mesh Size (in)	Refinement Point Size (in)	Nodes	Aspect Ratio	Max von Mises Stress (psi)	Max von Mises Strain
0.25	0.03125	1506	10.12	165.1	0.13
0.125	0.03125	1525	7.17	173.8	0.14
0.125	0.03125	1842	6.53	161.3	0.12

For the refinement points, the effective radius was 0.0625 in. For the final mesh, refinement points were added on the inner surface of the hole. As we can see from the results presented in the table, the model converged after two meshes. Convergence was determined to be achieved because the results differed by only 7.19%.

The maximum von Mises stress was located as shown in **Figure 7.3.3.7**:

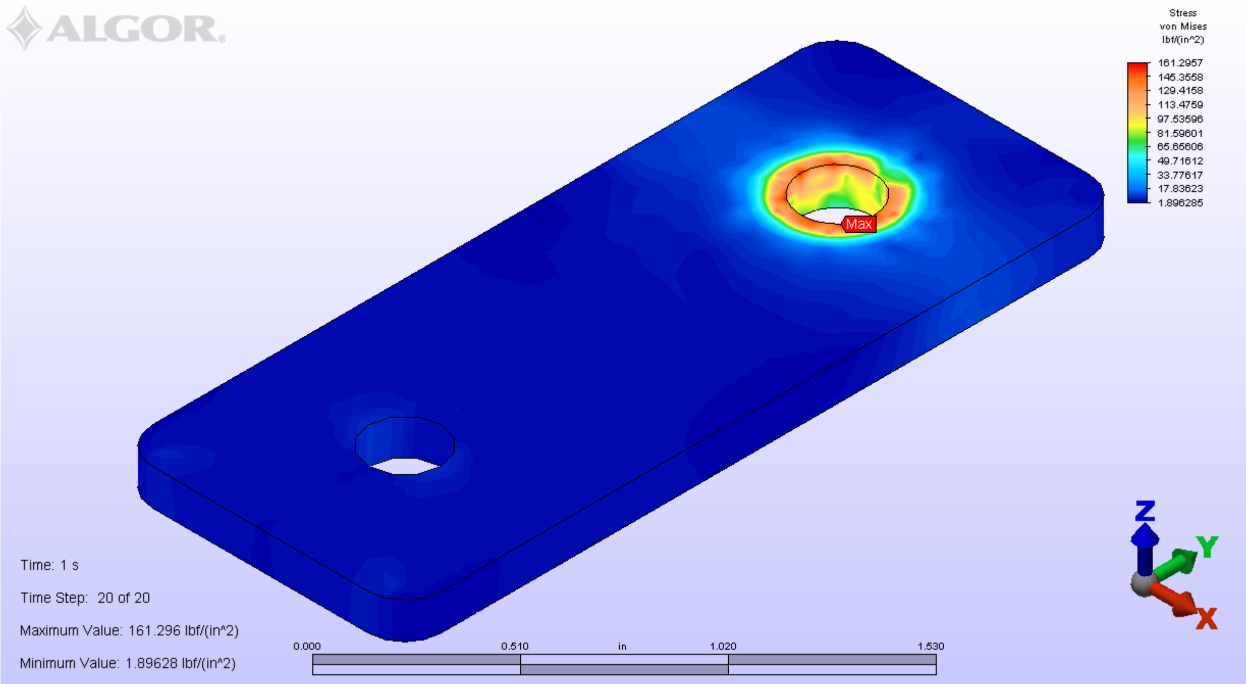

Figure 7.3.3.7. Location of Maximum Stress

The location of the maximum von Mises strain is shown in **Figure 7.3.3.8**:

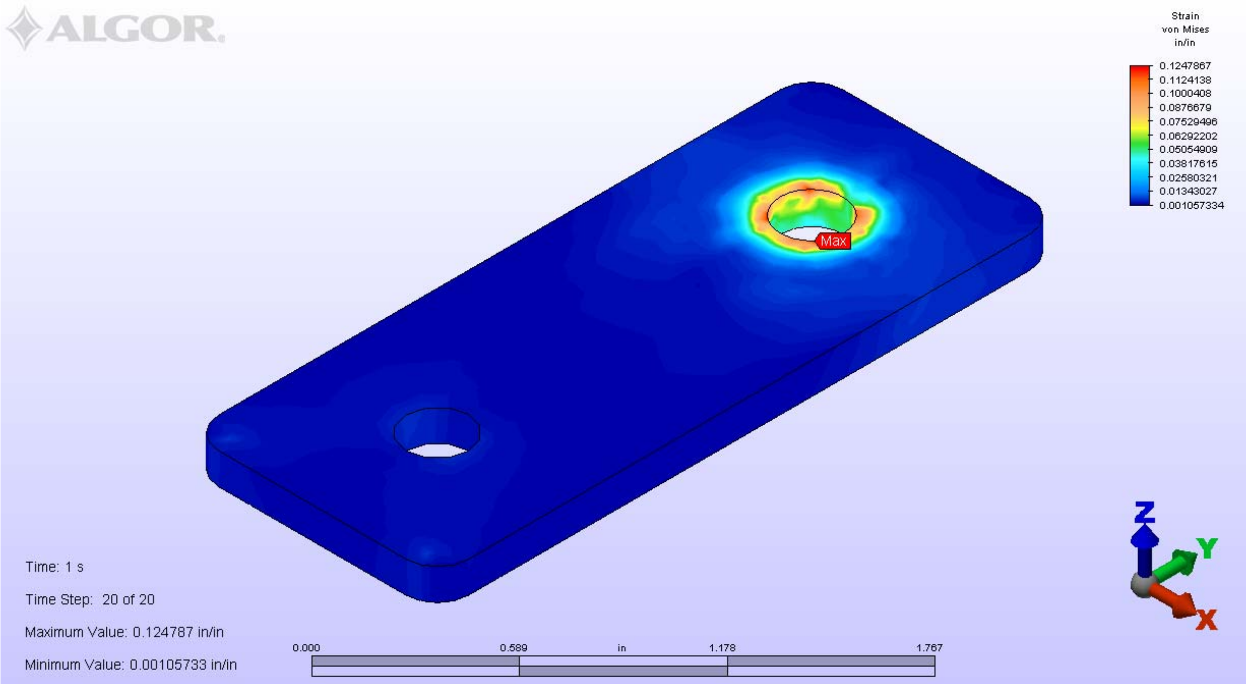

Figure 7.3.3.8. Location of Maximum Strain

Because the maximum stress value was less than the 319.1 psi fatigue strength for 1.5 million cycles, we have concluded based on our FEA results that the rubber layer meets the requirement that its lifetime not be less than one year. In the case that the rubber sheet fails before one year, we have designed the rubber sheet with two holes. Thus, the user can take the rubber sheet out of the slot, flip the rubber sheet over, and insert the rubber back in so that the second hole is used. Thus, we have minimized material cost by utilizing more of the material.

7.4 Prototype Manufacturing

Each prototype was manufactured independently. Since we used HDPE for most of the prototype material, we used a CNC mill for precise manufacturing of the prototypes.

For the large O-ring fixture, the prototype manufacturing followed the procedure described later in this report for the final design manufacturing.

For the medium o-ring device, the prototype was manufactured using scraps of pine wood. The base feature was made from wood. Sides were built on top of the base, making the base hollow inside. Initially, we experimented with using rubber to act as a cushion, similar to the final design of the small o-ring device. A layer of rubber was used with a small hole cut out to allow for the part during installation. This method work well as far as installing the o-ring, but once the o-ring was installed; pulling the part with the o-ring back through the rubber was a problem. A high force was required to pull the part back through, somewhere along the order of twice as much effort to pull the finished part back through the rubber as pushing it. This it was apparent this issue needed resolved. Through addition experimentation with different group member's ideas, the one that seemed to work the best was the use of steel rods. The o-ring is placed on top of two equal rods that are pulled together by elastic bands and separated by a wood boss in the center. Force tests were performed using this method and were satisfactory. The use of two rods to install the o-ring onto the medium part was carried through to the final design.

For the final design, the base was manufactured from HDPE. The basic shape of the base was initially cut to shape using a vertical band saw. A CNC mill squared the sides of the base and machined the necessary pockets to equip the base with the installation rods. Stainless steel rods were chosen for the final design. The rods offer corrosion resistance and excellent wear resistance. When experimenting with the prototype, it was determined that an "o-ring set guide" would be needed for easy o-ring placement. For the final design, a set guide was manufactured from HDPE and placed on a spring that returns the set guide back to its original location once a part is finished.

The manufacturing procedure followed for the manufacture of the small O-ring fixture also employed the use of numerous mock-ups. Mock-ups were used to test various design features before these features were actually added to the prototype. The small O-ring fixture prototype was manufactured in the same manner as described later in this report for the final design manufacturing process. However, when this prototype was constructed, the manufacturing process was not completed in a perfectly systematic manner. The plastic base was cut with a band saw and the top surface milled out to provide for the pocket and walls. The top cover was milled out of some of the excess plastic and glued onto the base. The surface of the base was

then further milled down to obtain a uniform surface. The holes for the rubber feet were drilled out and the feet installed. Then the rubber was cut, sanded down so that it fit in the pocket and installed into the pocket in the base. Finally, a slope was milled out of the top surface.

7.5 Prototype Testing

The primary objective of our prototype testing was to determine and measure the ease of use of the three fixtures we designed. In addition, we also tested our prototypes to determine productivity rates associated with the use and operation of the fixtures. Because we developed three separate fixtures, each design to assist with the installation of different sized O-rings on different sized and shaped parts, we had to independently test each of the three prototypes.

We designed two specific experiments to measure the performance of the prototypes we constructed. The first test was a force measurement test designed to measure the ease of use associated with the operation of our fixtures. Ease of use is here defined to be measured by the minimum input force required to successfully install an O-ring. The second test we performed was designed to measure the productivity rates using our fixtures compared to the productivity rate of installing O-rings by hand. Here productivity is defined as the number of O-rings successfully installed in a specified period of time.

7.5.1 Input Force Measurements

In performing this experiment, an approximate required input for will be known. Using an accurate force gauge will enable the experiment to produce accurate results. The experiment is designed to easily determine a required input force for each of the o-ring installations. A target input force would be about 15 pounds. This target input force was calculated based upon the maximum force a single finger can exert. According to one study we found, the maximum force exerted by a single finger is approximately 100 N (22.7 lbsf) [16]. Since we are designing these fixtures for comfort, we determined that a comfortable force would be 2/3 of this maximum force. Thus, the target value for the input force is 15 lbsf for the medium and large fixtures. Since the input force for the small o-ring fixture is applied over an extremely small area (only a fraction of the surface area of a single thumb), we determined that our target value should be 50% of the maximum force. Thus, the target value for the small fixture is 11 lbsf. The insertion force will be much greater than the extraction force; however only one design will have an extraction force.

The experiment involves placing an o-ring into to its appropriate slot and then taking the o-rings respective part and pressing it into the fixture. The input force will be measured during the pressing process. This experiment is relevant to the overall design and satisfaction of the customer because it will help to determine whether the design is capable of meeting the customer requirements as well as improving their process. If the force is too large, changes or adjustments must be made to the design.

The following procedure was used to conduct this input force experiment:

1. Calibrate force sensor

2. Connect force sensor to plastic part
3. Place fixture on platform
4. Set the o-ring in the stop on top of the fixture.
5. Place the part on top of the o-ring and press down on the part until the part pushes through the rods and the o-ring is in place
6. Repeat steps 1-5 until sufficient data points are collected

The experimental setup for the test applied to the medium O-ring fixture is shown in **Figure 7.5.1.1**. We used this same setup for the large O-ring fixture as well.

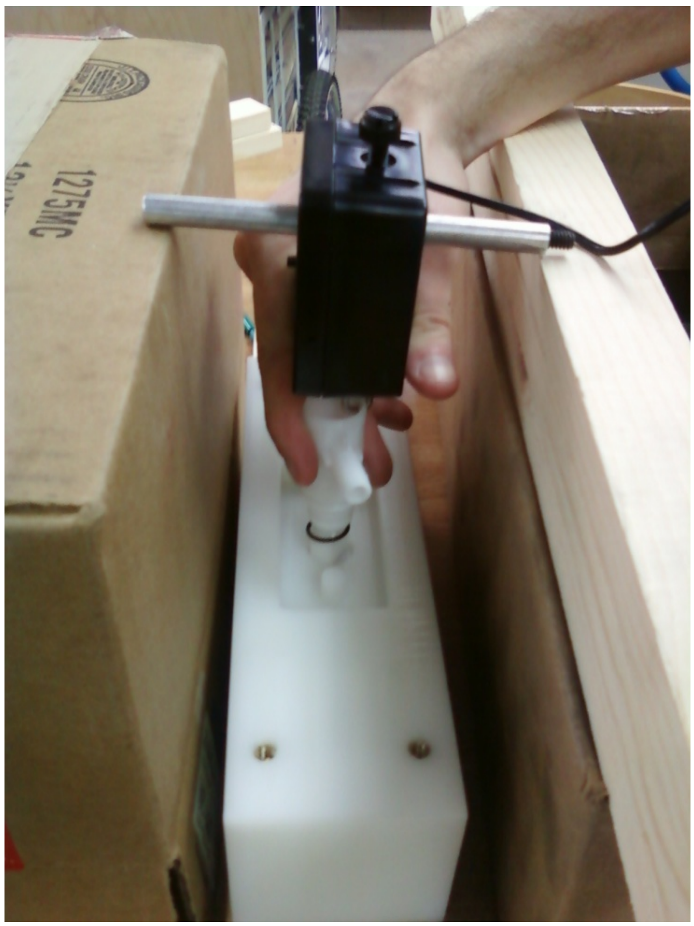

Figure 7.5.1.1. Experimental Setup for Input Force Testing

Figures 7.5.1.2 and **7.5.1.3** show the experimental setup for the input force testing for the small O-ring fixture. Using this procedure, we calibrated the force sensor by placing the unloaded fixture onto the scale and set the measured force to zero. We then installed the O-ring onto the part by pressing the part into the fixture. The scale then measured the input force required to install the O-ring successfully.

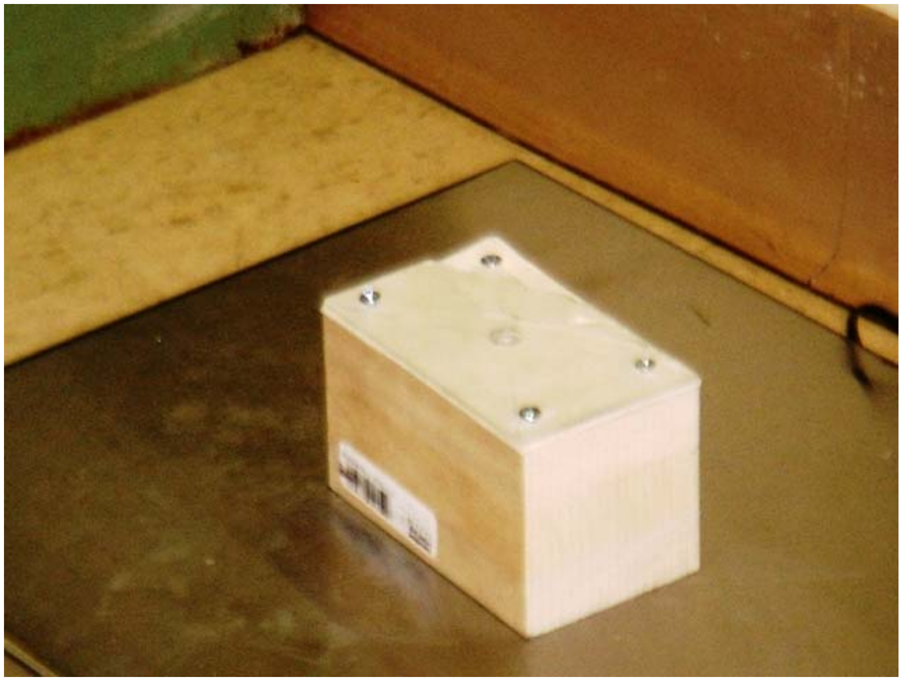

Figure 7.5.1.2. Fixture on Scale

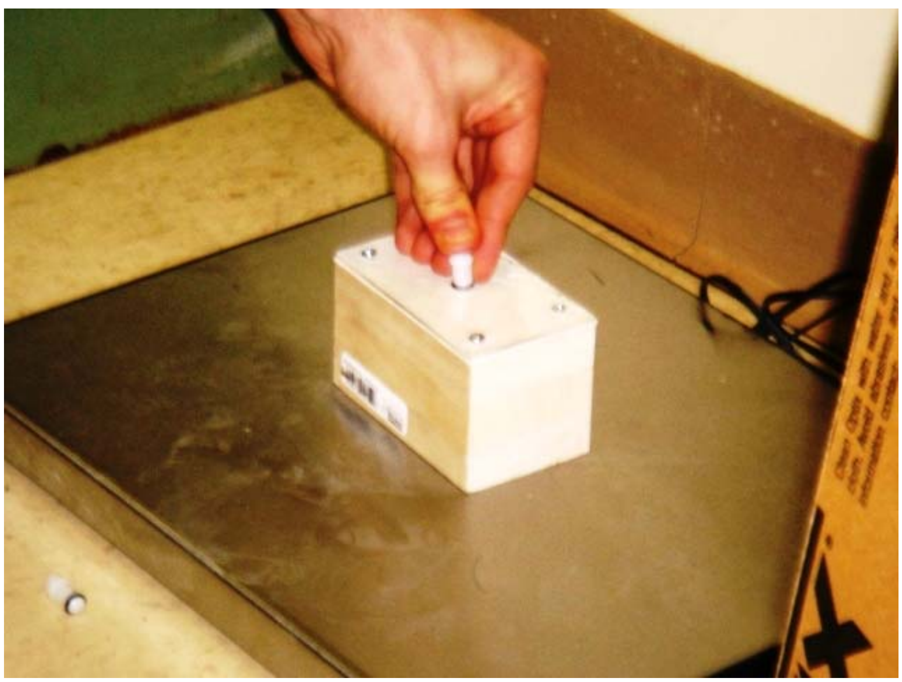

Figure 7.5.1.3. Installing O-ring

The force-time profile for the input force for the large O-ring Fixture is shown in **Figure 7.5.1.4** which shows results for multiple trials. According to this data, the force builds up to the point where the o-ring is installed and then rapidly decreases to zero. **Table 7.5.1.1** shows the summary for the maximum force during the installation motion.

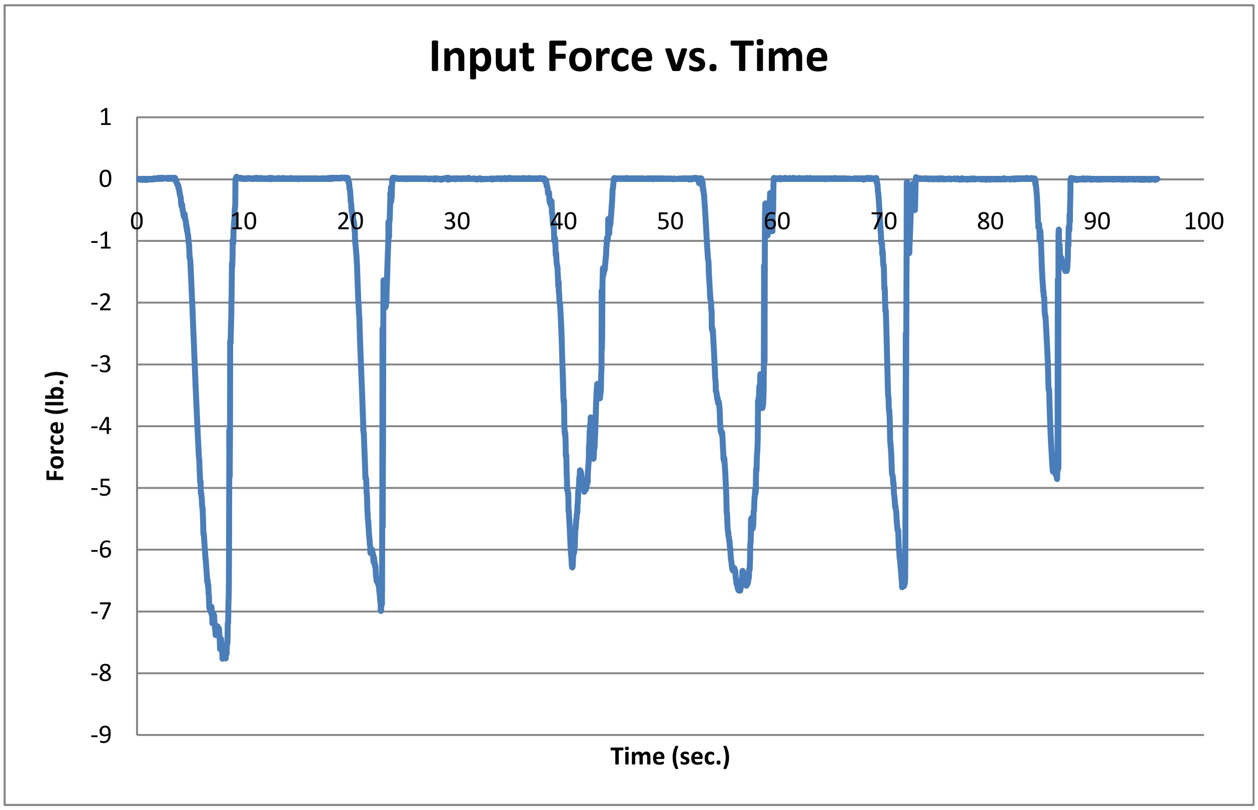

Figure 7.5.1.4. Force-Time Profile for Large Fixture

Table 7.5.1.1. Input Force Testing

(4 wraps of rubber band)	
Trial	**Input Force (lbs)**
1	7.19
2	7.74
3	6.99
4	6.67
5	6.65
6	7.18
7	6.23
8	7.65
9	6.92
10	8.65
Average	**7.19**

From these results, we see that the maximum input force required to install the o-rings is slightly over 7 lbsf. The input force, though, is less than half of the maximum required force we determined for our fixture; therefore, the large O-ring fixture test indicates that our design met this technical specification.

Preliminary input force data for the medium O-ring fixture is given in **Table 7.5.1.2**.

Table 7.5.1.2. Medium O-ring Force Data: Preliminary Results

Input Force Testing (4 wraps of rubber band)		**Input Force Testing (3 wraps of rubber band)**	
Trial #	Input Force (lbs)	Trial #	Intput Force (lbs)
1.0	17.6	1.0	14.4
2.0	15.8	2.0	14.8
3.0	18.0	3.0	13.4
4.0	16.6	4.0	15.2
5.0	23.4	5.0	13.2
6.0	22.2	6.0	14.0
7.0	18.2	7.0	11.6
8.0	16.0	8.0	12.4
9.0	12.8	9.0	13.6
10.0	15.0	10.0	12.9
Avg.	**17.6**	Avg.	**13.55**

Our preliminary results for the medium o-ring, (**Table 7.5.1.2**) show how the input force is affected by ranging the rubber bands elastic constant, thus the number of wraps of the band. Having four wraps, the maximum input force was 23.4 pounds. An average force over ten trials is 17.6 pounds. With 3 wraps, the o-ring continued proper installation and the input force decreased. The maximum input force was 15.2 pounds with an average force of 13.55 pounds. From our results, we see that the force to install the medium o-ring exceeds our target specification of 10 pounds. To address this, we plan on furthering our experimentation by performing tests with different elastic bands so that the o-ring installation is successful having an average input force of approximately 10 pounds. ?

Our final force tests for the medium fixture show how the input force varies with time in **Figure 7.5.1.5**.

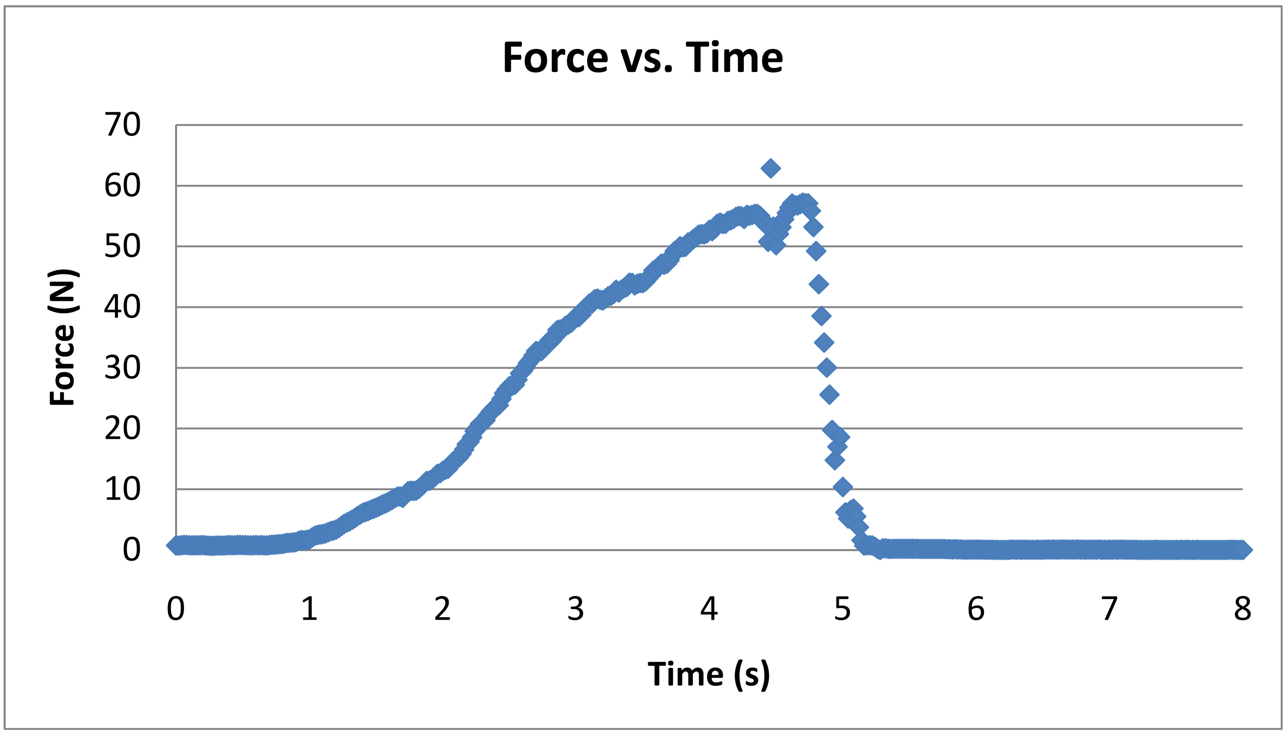

Figure 7.5.1.5. Force vs. Time Profile for Medium Fixture

This force-time profile shows that there are three distinct profiles: 1) as the metal rods are pushed outward as the part is pressed into the o-ring, 2) the maximum force occurs right before the o-ring rolls onto the part, and 3) as the part is extracted from the fixture. The maximum input force required is the value we are most concerned with. The following table summarizes the results for the maximum force applied.

Table 6 Final Results for Medium Fixture

Input Force Testing (1 Wrap of Rubber Band)		
Trial	**Force (N)**	**Force (lbf)**
1.00	55.95	12.58
2.00	56.44	12.69
3.00	62.85	14.13
4.00	59.11	13.29
5.00	62.85	14.13
Average	**59.44**	**13.36**

These results show that the average maximum force is 13.4 lbsf, less than our target value of 15 lbsf. This maximum force occurs the instant before the o-ring is installed onto the part.

For the small o-ring, **Table 7.5.1.4** shows the maximum force was determined to be 16.8 pounds. An average over 10 trials is 11.7 pounds. Using one's fingers to grip a small part causes discomfort after an extend period of time.

Table 7.5.1.4. Small O-ring Force Data

Input Force Testing	
Trial #	**Input Force (lbs)**
1.0	10.6
2.0	16.8
3.0	13.6
4.0	14.6
5.0	10.8
6.0	13.0
7.0	13.4
8.0	12.8
9.0	11.2
10.0	12.4
Avg	**11.7**

This input force exceeds the required input force maximum requirement of 11 lbsf. We determined that the chief cause for this excessive force was the rubber layer. Thus, we decided

that we needed to select a different rubber material which had a greater flexibility instead of the current rubber material we used. We replaced the Nitrile aka Buna-N rubber (stretch limit of 300%) with Natural Latex Rubber (stretch limit of 810%).

7.5.2. Time Trials

In performing this experiment, a relative approximation of efficiency of the fixture can be determined. The clients that will be using this design have mental and physical disabilities, thus it would be difficult to simulate their compatibles to install an o-ring. Measuring the time of a normal person to install o-rings and comparing with and without using the fixture will help to determine how well the device performs. This experiment will show that using the fixture is more time effective than installing the o-rings by hand.

The experiment involves recording the times of two processes; the process of installing o-rings by hand, and the process of installing the same o-rings using the designed fixture. This experiment is significant because it determines the effectiveness of the design. A relative efficiency scale can be determined by comparing the installation times by hand to those using the fixture. The main purpose of the design is to improve the customer's assembly performance. Reducing the installation time for such a repetitive motion will improve their productivity. If the installation time is more using the fixture than by hand, then using the design is nearly pointless.

The following procedure was conducted independently for the three prototypes:

1. Have multiple parts with their respective o-rings (at least 10 of each) unassembled laying on a flat surface.
2. Grab a single part and a single o-ring by hand and install the o-ring onto its part. Once the o-ring is installed placed the assembled part aside or into a separate bin.
3. Use a stop watch to record the time it takes to install all o-rings onto all parts from the time first contact is made with an o-ring until the final assembled part is placed in the bin.
4. Using the fixture, place same amount (as in part 1) of o-rings onto the space provide for the o-rings and set the parts to the side on the table.
5. Slide an o-ring from the group into the appropriate slot of the fixture.
6. Take a part from the table and insert it onto/into the fixture, installing the o-ring. Then place the part into a separate bin.
7. Record the time it takes to install all o-rings onto their respective parts. Start the time at the first contact of an o-ring and end the time when the final assembled part is placed in the bin.

The experimental results for time trials are shown in **Tables 7.5.2.1**, **7.5.2.2**, and **7.5.2.3** for the large, medium, and small O-ring fixtures respectively. For these tests, we measured the

prototypes ourselves and not the employees of our customer. Thus, this data should not be definitive in assessing the actual productivity of employees with disabilities. These data do, however, give a rough estimate of productivity rates for our fixtures compared to hand installation.

Table 7.5.2.1. Large O-ring Time Data

8 o-rings by hand (seconds)	8 o-rings using prototype (seconds)
27	TBD

Table 7.5.2.2. Medium O-ring Time Data

8 o-rings by hand (seconds)	8 o-rings using prototype (seconds)
30	36

Table 7.5.2.3. Small O-ring Time Data

8 o-rings by hand (seconds)	8 o-rings using prototype (seconds)
35	54

From the time results, the prototypes did not improve our times compared to hand installation. We determined since we do not have dexterity limitations, these results should have reverse affect for our customer, thus our prototypes are designed to help once with limited dexterity.

Time was recorded based on the total amount of time it took for one of our team members to install 8 o-rings for each small, medium, and large parts. **Table 7.5.2.3** shows the total time for the small o-rings to be 35 seconds by hand and 54 seconds using fixture. For the medium o-rings, the total time was 30 seconds by hand and 36 seconds with fixture, **Table 7.5.2.2**, and 27 seconds by hand for the large o-rings, **Table 7.5.2.1**. From performing this experiment, a lot of time was used during picking up the o-ring from the table and setting it into it proper location for installation.

Our desired time to install the large O-ring onto the QCD shaft would be eight seconds. Timing some of the SW employees, (during fall quarter), we found that it takes them an average of 15 ± 5 seconds to install the o-ring by hand. Handling of the o-rings seemed to be the main cause for slow installation times. We feel that our installation time will be around 5 seconds / part. For the SW employees, 10-15 seconds is more likely at the beginning of testing. We are hoping that they will catch on and reduce their times to 8 seconds. However, once we have delivered the tool to them, we can easily monitor their daily production rate, and compare it to their rate without the tool. We feel very strongly that this design could reduce shoulder, and hand fatigue, by designing a tray large enough to rest their hands on, as they simply slide the o-rings. Even if their installation times are slower than what we hope for, we feel that reducing fatigue could keep employees more interested, thus increasing daily production rates.
To reduce the o-ring installment time for each o-ring, we plan to include o-ring trays with our prototypes so that the range of motion between o-ring placements is reduced.

By hand it took 35 seconds and with the fixture it took 54 seconds. The main explanation for this is that the time trial was performed by capable individuals and there was no time lost in the handling of the o-rings, which is where S.W. Resource's employees lost most of their time.

The time trial for this o-ring resulted in 30 seconds by hand and 36 seconds using the fixture. It's important to note that the o-rings were picked up by hand and placed on the set piece rather than slid onto it because the current prototype does not have a cover. This may be one reason for the increased time with the fixture. Once again the individual tested did not have trouble handling the o-ring, while the employees at S.W. Resources will run into that problem.

The team did run a time trial and it took 27 seconds to install 8 O-rings for the large O-ring.

8.0 Design Refinement for Production

The final prototype for the large o-ring installation was the most challenging to select, because the geometry of the "stem" part does not allow for the o-ring to simply slide into the groove. To gather different concepts we simply studied the part and the o-ring as a team. While searching for different concepts to install the o-ring, we found that the most reliable method was to align the part nearly perpendicular to the o-ring, and roll the o-ring over the part head and into the groove. From this we came up with two different concepts and used FMEA to select the different concepts.

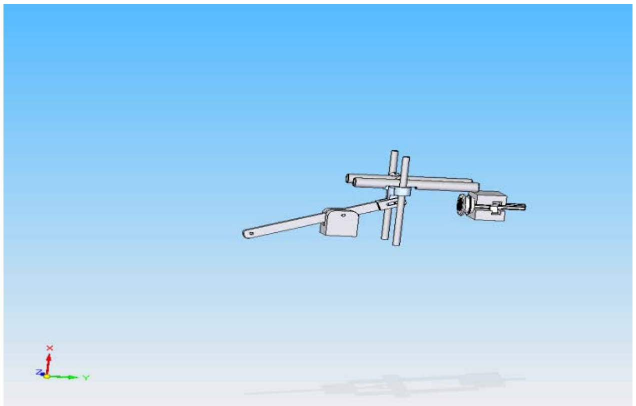

Figure 8.0.1. Concept one for large o-ring.

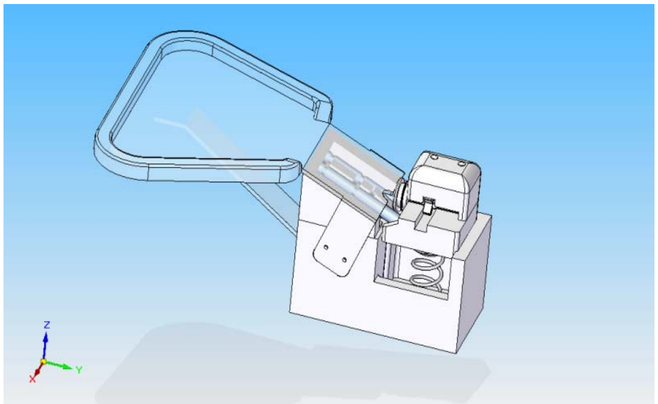

Figure 8.0.1. Final design selection

The first concept, much like the final design, utilized steel rods to slip the o-ring onto the stem. One key difference between the two was the moving parts. The first concept held the part stationary and used a lever arm and bracket to move the rods over the stem, while the final design holds the rods stationary, and allows the part to move vertically through the rods. Comparing different failure methods we decided that concept one had more failure modes due to the complexity of the moving parts. Potential failure modes for concept one:

- Bracket does not support the rods.
- Pins holding lever arm shear.
- Lever arm bending after prolonged use.

- Many pinch points.
- Spring failure at the end of rods.

All of these failure modes were given a severity of 9, as any of these failures will cause catastrophic failure, and a probability of occurrence of a 7, since the number of moving parts and everyday use will cause parts to wear at a faster rate. Safety was also a major concern with this concept; too many pinch points, and sharp edges. The final concept was selected as we determined that it would be safer, more reliable, durable, and easier to use.

This device is comprised of four basic components (see **Figure 9.1.1.1** later in this report): platform and part holder, base, stainless steel rods / rubber bands, and a Lexan tray. The base design is the main component of the system. Manufactured from HDPE the base's functions include, guiding the platform, holding the steel rods, and supporting the tray. The pockets, within the base were machined using Master Cam and CNC. The angled section holding the rods was machined separately and mounted to the base using four 8-32 hex cap screws, and brass inserts glued into the base.

The platform and part holder were manufactured as two separate parts. They are bolted together using a three inch long 10-32 screw that extends to the bottom of the platform and held with a lock washer and lock nut, to keep the nut from working loose during operation. The platform was made to slide vertically within the pocket of the base; forcing the part down onto the o-ring and through the rods. The part holder was added later and was absolutely crucial in maintaining proper part alignment with the rods, during operation. It contains a groove specially made to fit the geometry of the stem, providing good alignment every time. All corners on the part holder were machined with a quarter inch radius, to make the device comfortable and easy to use.

The rods are the installation mechanism. They were chosen to be 303 SS, to meet the target specification of daily cleaning. Grooves were cut into the rods to provide a seat for the rubber bands. We found through testing that this reduced the friction between rubber bands and HDPE, allowing the rods to properly expand as the part is pushed between them.

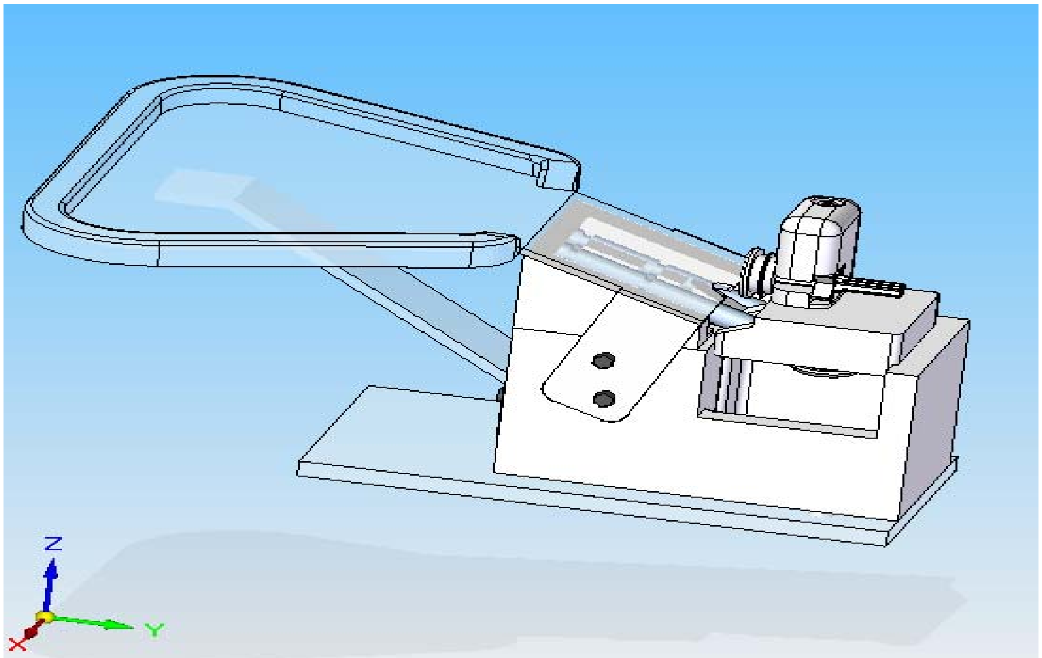

Figure 8.0.3. CAD Model of Large O-Ring Fixture

9.0 Final Design for Production

9.1 Design Description and Operation

The following sections describe the design and operation of each of our fixtures. For more details, the User Manual is included in **Appendix E** and our technical engineering drawings are included in **Appendix F**.

9.1.1 Large O-Ring Fixture

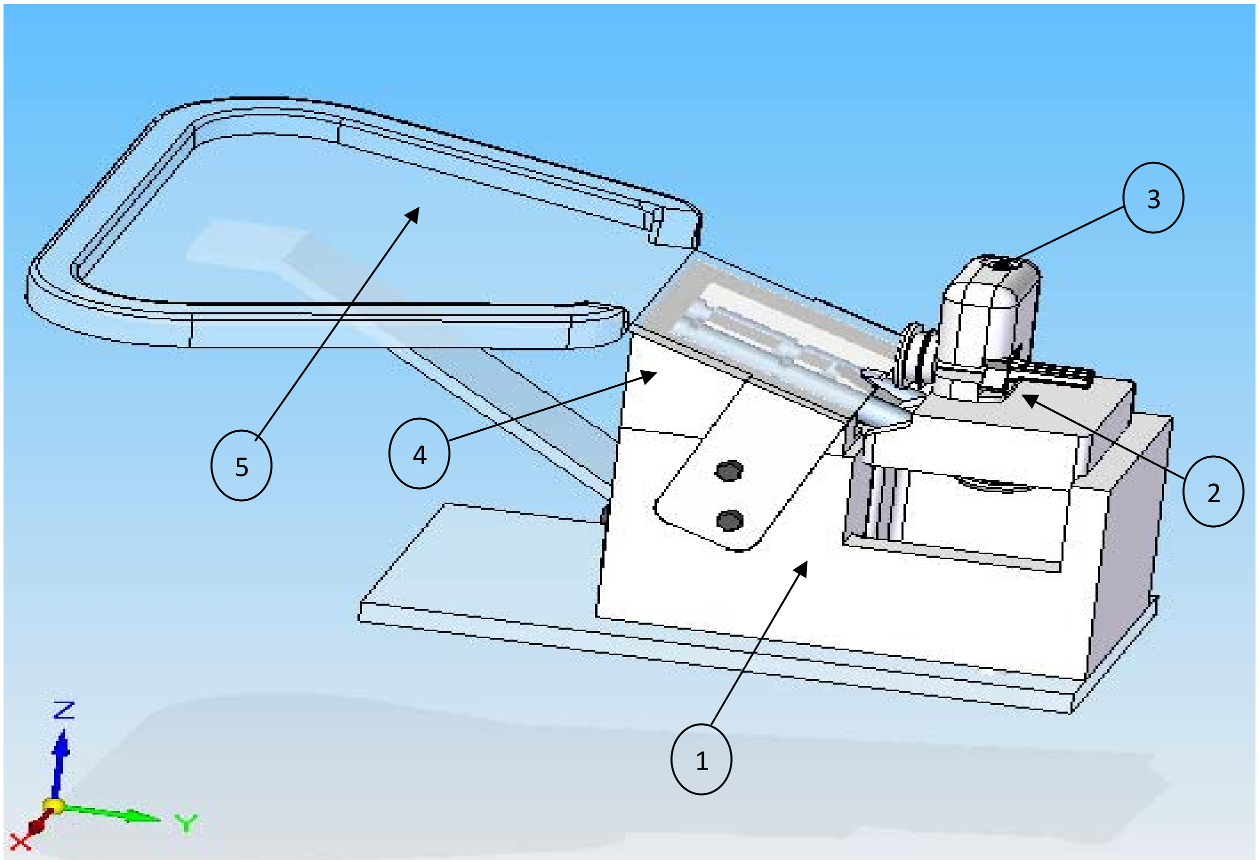

Figure 9.1.1.1. CAD Model of Large O-ring Fixture

The design for the large o-ring fixture can be seen in **Figure 9.1.1.1**. Its operation is to install an o-ring onto a specific part referred to as the stem. The stem has an odd shape and required a slightly different design. The base function utilizes two stainless steel rods held in tension by rubber bands. The rods in tension apply pressure to the head of the stem. As the stem head is forced through the rods, the o-ring is forced to slip around the head of the stem. See the User's Manual for proper operating instructions and safety precautions. As found in **Figure 9.1.1.1**, the main components of the design are highlighted.

The design drawings for these components can be found in **Appendix F**. The design drawings for these components can be found in the Appendix. Number 1 is the base; Number 2 is the platform; Number 3 is the part holder; Number 4 is the angled top; Number 5 is the tray. For simple operation the user would slide an o-ring from the tray into the preferred slot on the platform. Then the user would install a part into the part holder. The user would then press down on the part holder, forcing the o-ring to slip around the part as the rods expand around the stem head. This is summarized in **Table 9.1.1.1**.

Table 9.1.1.1. Component Parts of Large O-ring Fixture

Part Number	Part Description
1	HDPE Base
2	HDPE Platform
3	HDPE Stem Holder
4	HDPE Inclined Rod Base
5	Lexan Part Tray

9.1.2 Medium O-ring Fixture

Figure 9.1.2.1 shows the final CAD model design for the Medium O-ring fixture.

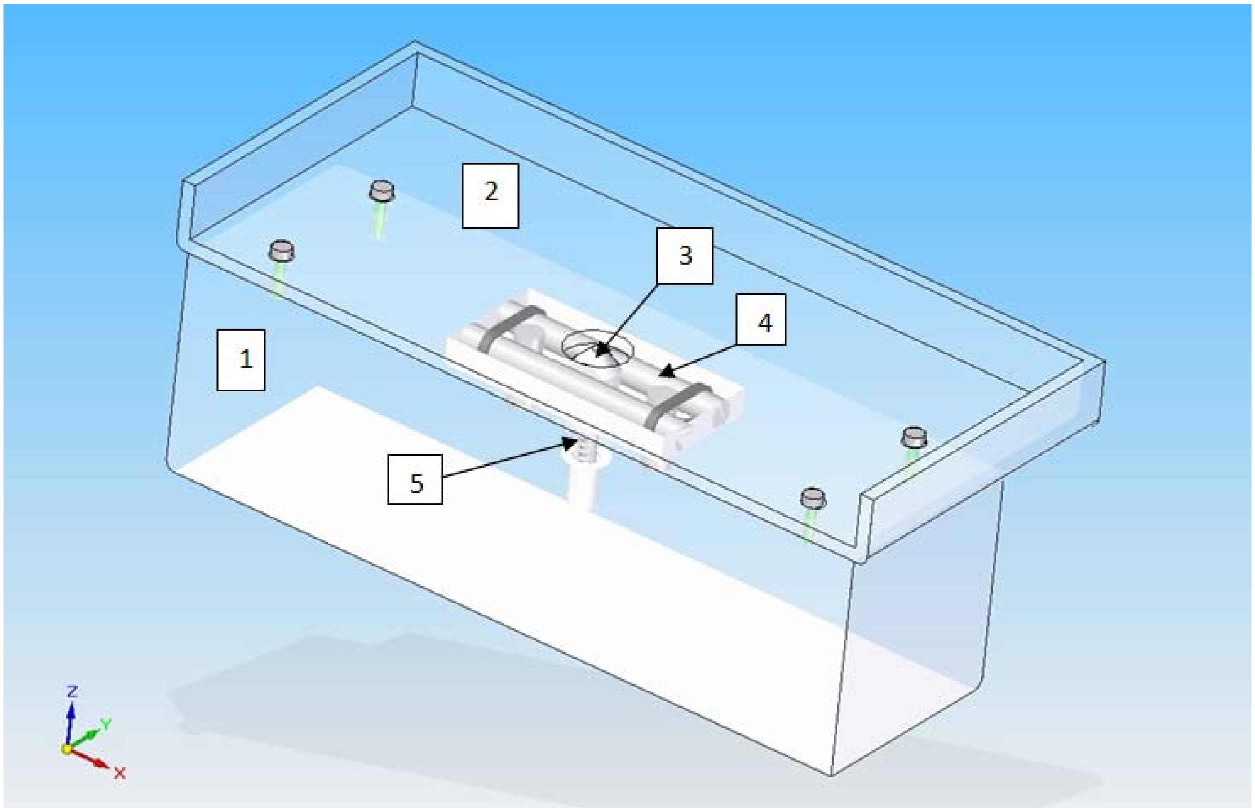

Figure 9.1.2.1. Solid Model of Medium O-ring Fixture (Final Design)

Like the large O-ring fixture, its operation is to install an o-ring onto a specific part referred to as the nozzle housing or medium part. The part has a tapered head, which assists in helping the o-ring "roll" into place. The base utilizes two stainless steel rods held in tension by two elastic bands. As the housing is pressed downward through the rods, the o-ring is forced to slip around the tapered head of the part as the rods apply pressure on the part below the o-ring. Refer to the User's Manual for proper operating instructions and safety precautions.

The design drawings for these components can be found in **Appendix F**. Number 1 is the base; Number 2 is the o-ring tray; Number 3 is the o-ring set guide; Number 4 represents the stainless rods; Number 5 is the return spring for set guide. The user slides an o-ring from the tray to the set guide, where it is placed over top. The user takes a housing part and presses it, head first, onto the set guide until the part will not press any further down. This is enough to install the o-ring. The user the pulls the part back up and places the finished part into a parts bin.

9.1.3 Small O-ring Fixture

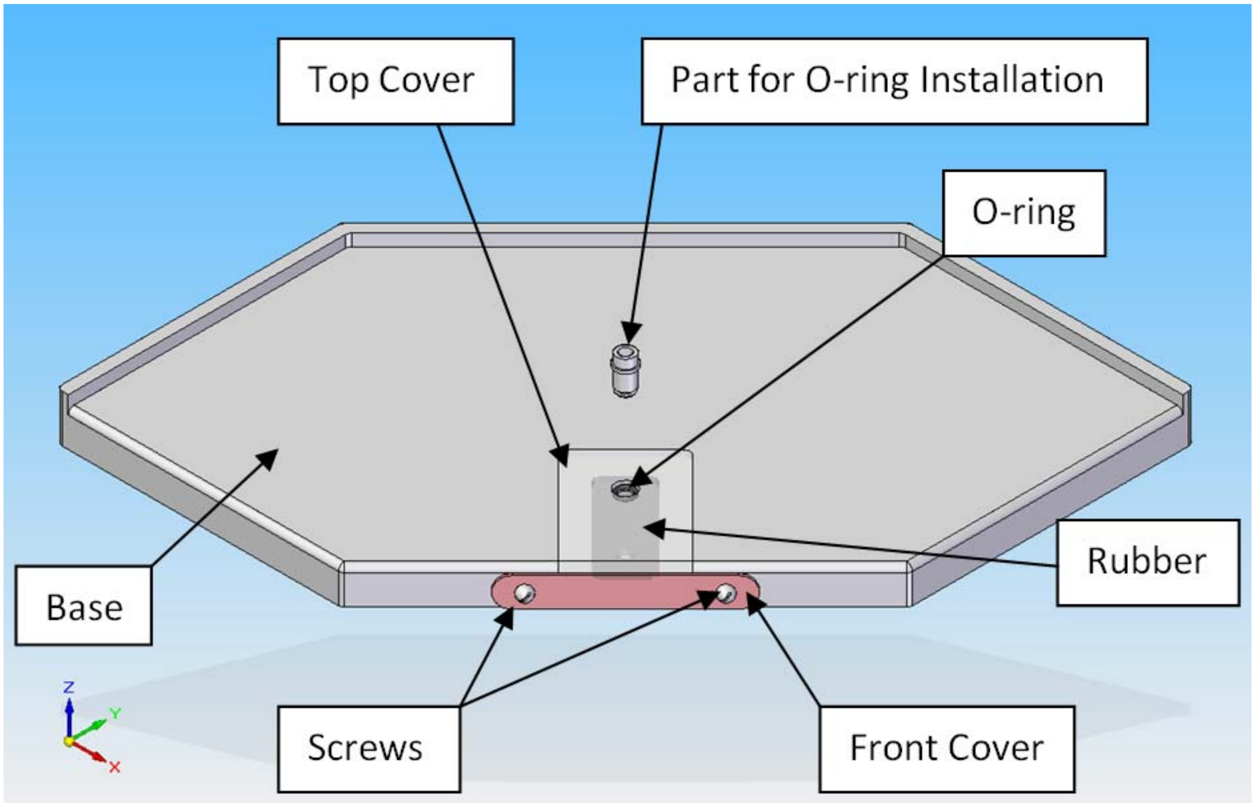

Figure 9.1.1. Small O-ring Fixture Final Design

The final design for the small o-ring fixture consists of five different parts as seen in **Figure 9.1.1.** The base, top cover, front cover, rubber and two screws. The fixture operates in two quick steps. The first step is to slide an o-ring into the hole of the top cover, locating the o-ring on top of the rubber. The user then picks up a part and presses down on the o-ring and the rubber will force the o-ring over the chamfer of the part. It is important for the user to correctly orient the part for installation. The part must be inverted so that the tip of the part is pressed down into the hole and into the O-ring. The plastic base acts as a hard stop for pressing the part into the hole. When the rubber layer is compressed to the maximum allowed by a 15 lb input force (the approximate maximum force that a user will apply), the part can no longer be pressed down unless significantly more force will be applied. More detailed instructions and precautions can be found in the **User's Manual** in **Appendix E**.

9.2 Cost Estimation and Manufacturing and Assembly Processes

9.2.1 Large O-ring Fixture

Many of the components of the design are made from HDPE and required intricate milling for precise geometry. In order to satisfy this design, CNC milling is required for many of the parts including: the base, the angled top, the platform and the part holder. The tray and bottom stabilizer can be made from use of a band saw and sheet metal bender. The surface finish is acceptable from the finishing left from the milling. Drawings of these parts can be found in the **Appendix F**.

Many of the components of the design are made from HDPE and required intricate milling for precise geometry. In order to satisfy this design, CNC milling is required for many of the parts including: the base, the angled top, the platform and the part holder. The tray and bottom stabilizer can be made from use of a band saw and sheet metal bender. The surface finish is acceptable from the finishing left from the milling. All manufacturing operations are subject to the capabilities of the manufacturer. The standard tolerance for all parts in the Large O-ring Fixture is ±0.005”. The materials for each part are listed on the drawings.

Table 9.2.1.1. Cost Estimation for Large O-ring Fixture

Cost Details for Large O-ring Fixture (assembly-line production)								
	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	Operation 8
	Base	Angled Top	Platform	tray	rods	part holder	spring bosses	assembly
a. Total time to complete operation (in hours)	1.5	1.5	1	0.75	1	1	0.25	1
b. Labor rate for the operation	$20	$20	$20	$12	$15	$20	15	12
c. Labor Cost {c = a×b}	$30	$30	$20	$9	$15	$20	$4	$12
d. Basic overhead factor	1	1	1	1	1	1	1	1
e. Equipment factor	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0
f. Special operation/tolerance factor	0.25	0.25	0.25	0	0	0	0	0
g. Labor/overhead/equipment cost {g = c × (1+d+e+f)}	$83	$83	$55	$23	$38	$50	$9	$24
h. Purchased Materials/Component Cost	$25	$10	$10	$5	$3	$8	$1	N/A
TOTAL	$424							

The fixture costs can be seen in **Table 9.2.1.1**.

9.2.2 Medium O-Ring Fixture

The medium o-ring fixture is simple to assemble. The manufacturing aspect is complex. Following the steps below in conjunction with the assembly/part drawings given in Appendix F, manufacturing is quite simple. Overall, the small o-ring fixture was relatively easy to manufacture and assemble.

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All operations performed on a CNC vertical mill unless otherwise stated in the following procedure.

1. Rough cut the basic shape of the base; 10” X 3” X 2.75”, using a vertical band saw. Square sides of base using a CNC or Vertical Mill.

2. Mill out top pocket of the base, leaving two 0.375” diameter bosses.

3. Plunge drill a 0.375” diameter hole, 1.965” center of pocket.

4. Using a 0.625” counter bore, drill center hole 1.305” deep

5. Four 0.190” mounting holes, 0.375” deep are placed symmetrically around the top of the base to allow brass inserts to be place.

6. Machine set guide from HDPE; 0.625’’ diameter. Counter bore 0.375” diameter, 0.25” deep in the bottom of guide. This allows spring to seat into guide.

7. Using adhesive, glue a 0.375” spring into the base of guide.

8. Use adhesive to glue the brass inserts into the four tray mounting holes.

9. Place set guide and spring into center hole.

10. Cut two 0.375” diameter 304 stainless steel rods roughly 3.250” in length using horizontal band saw.

11. Take cut rods to a lathe to cut grooves 0.250” from each end.

12. Using a carbide grooving tool, cut grooves roughly 0.250” deep and as wide as the tool.

13. Remove burrs from rods and install 2 wraps of an elastic band at each end.

14. Place rods with bands attached into milled pocket of bass and allow rods to close against the bosses.

15. For the o-ring tray, cut out a square piece of 0.125” thick lexan based from the drawing dimensions.

16. Using a sheet-metal brake, bend 3 sides, both short and one long, to a 90 degree angle.

17. Using a 0.625" hole saw on a vertical drill press, cut out hole in center of tray.

18. Remove plastic from lexan and set on top of base. Using a marking utensil, mark out the four mounting holes to mount the tray. Use an electric drill with 0.250" drill bit to drill the holes.

19. De-burr holes

20. Assemble tray and other parts based on assembly drawing.

The cost estimation for the medium O-ring fixture is given in **Table 9.2.2.1**.

Table 9.2.2.1. Cost Analysis for Medium O-ring Fixture

Cost Details for Medium O-ring Fixture (assembly line production)						
	Cut base per DWG# T5-M01	Machine base per DWG# T5-M02	Cut rods and apply grooves per DWG# T5-M04	Cut Lexan, bend, drill per DWG# T5-M03	Machine guide per DWG# T5-M02	Final Assembly
Total Time	0.25	1.5	1	0.75	1	0.5
Hourly Rate	$12	$20	$15	$12	$20	$12
Labor Cost	$3	$30	$15	$9	$20	$6
Overhead Factor	1	1	1	1	1	1
Equipment Factor	0.5	0.5	0.5	0.5	0.5	0
Special Operation/Tolerance Factor	0	0	0	0	0	0
Labor/Overhead/Equipment Cost	7.5	75	37.5	22.5	50	12
Materials Cost	$40	N/A	$7	$25	N/A	$10
Total Cost	$287					

9.2.3 Small O-Ring Fixture

The cost estimate for the Small O-ring fixture is shown in **Table 9.2.3.1**.

Table 9.2.3.1. Final Design Cost Analysis for Small O-ring Fixture

Cost Details for Small O-ring Fixture (assembly-line production)									
	Operation 1	Operation 2	Operation 3	Operation 4	Operation 5	Operation 6	Operation 7	Operation 8	Operation 9
	Cut HDPE base	Mill out top surface and walls on base; mill out pocket on base	Mill out top HDPE layer for pocket	Install top layer for pocket	Mill top surface down; mill out slope	Cut rubber layer; cut out hole in rubber layer	Drill holes for screw inserts and feet; install inserts and feet	Cut and install front cover	Inspection, cleanup, etc.
a. Total time to complete operation (in hours)	0.25	0.5	0.5	0.25	0.5	0.5	0.5	0.5	0.5
b. Labor rate for the operation	$15	$20	$20	$12	$14	$15	$12	$12	$12
c. Labor Cost {c = a×b}	$4	$10	$10	$3	$7	$8	$6	$6	$6
d. Basic overhead factor	1	1	1	1	1	1	1	1	1
e. Equipment factor	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0
f. Special operation/tolerance factor	0	0.25	0.25	0	0.25	0.25	0	0	0
g. Labor/overhead/equipment cost {g = c × (1+d+e+f)}	$9	$28	$28	$8	$19	$21	$15	$15	$12
h. Purchased Materials/Component Cost	$23	N/A	N/A	N/A	N/A	$2	$4	$5	N/A
TOTAL	**$187**								

The total cost to produce one of these fixtures is estimated to be $190. Since the size of the raw materials were sometimes significantly larger than the size desired (i.e. the rubber sheet and screws), the cost was divided based on the amount of material used rather than using the total cost. This does not have a major effect on the final cost because the rubber sheet was $25.80 and the screws were $5.37. On all other materials the correct size was able to be purchased from the supplier.

Overall, the small o-ring fixture was relatively easy to manufacture and assemble, however the fabrication of the base and the top cover was more complex. To do this, follow the steps as given below in conjunction with the assembly/part drawings given in **Appendix F**.

1. Rough cut the opposite corners (from midpoint to midpoint) of the 12"x12"x1" HDPE using a vertical band saw. Face the new surfaces using a vertical mill to obtain the desirable surface finish.

2. Mill out both pockets of the base (T5-S-001) in which the rubber (T5-S-003) and top cover (T5-S-004) will later be attached.

3. Using scrap from step 1, mill out a piece of HDPE to the length and width (Note: the thickness will be milled down later) to be used for part T5-S-004.

4. Using an adhesive glue, glue the top cover (T5-S-004) to the base as seen in the assembly drawing.

5. Mill out the top face of the base (T5-S-001) and top cover (T5-S-004), giving a smooth surface finish where the top cover and the base parts meet.

6. Continue all other parts as seen in their respective drawings

7. Assemble all parts based on assembly drawing.

9.3 Design Drawings, Parts List and Bill of Materials

Design Drawings for all three fixtures are located in **Appendix F**. The Parts List and Bills of Materials are given for each of the three fixtures in the following sections.

9.3.1 Large O-ring Fixture

Figure 9.3.1.1 and **Table 9.3.1.1** give the parts list for the Large O-ring Fixture.

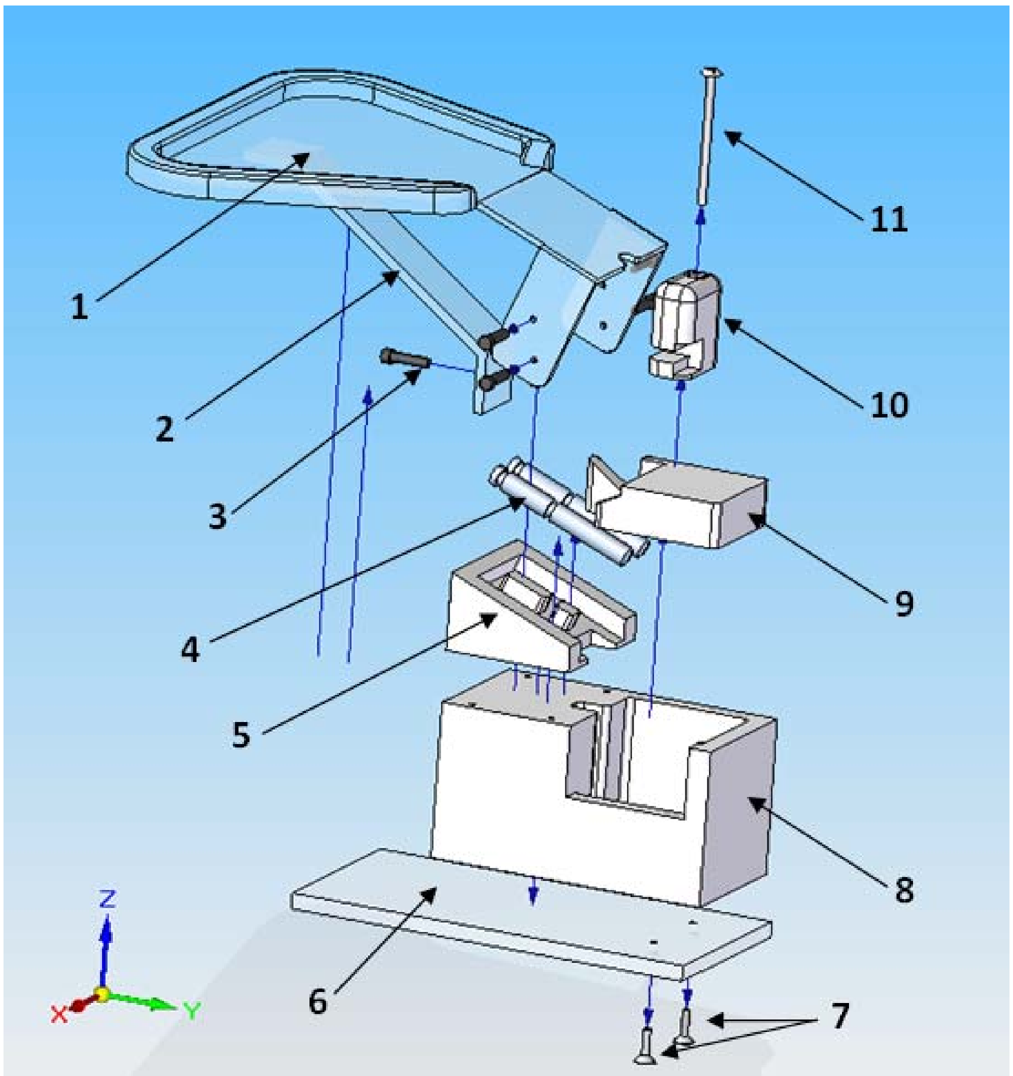

Figure 9.3.1.1 Large O-ring Fixture

Table 9.3.1.1. Parts List for Large O-ring Fixture

Part Number	Part	Material	Vendor
1	Tray	Lexan & HDPE rails	McMaster Carr/Athens Glass
2	Tray Brace	Lexan	Athens Glass
3	8-32 x 1" Hex Bolt : (5)		Lowes
4	316 SS $\frac{3}{8}$ in. rods	316 SS	McMaster Carr
5	Rod Holder	HDPE	McMaster Carr
6	Base	$\frac{3}{8}$ in. Plexi-Glass	McMaster Carr
7	Base Screws	1" coarse thread screws	Lowes
8	Box	HDPE	McMaster Carr
9	Platform	HDPE	McMaster Carr
10	Stem Holder	HDPE	McMaster Carr
11	Long Screw	$2\frac{1}{2}$ in. machine screw & nut	Lowes

9.3.2 Medium O-ring Fixture

Figure 9.3.2.1 and **Table 9.3.2.1** give the parts list for the Medium O-ring fixture.

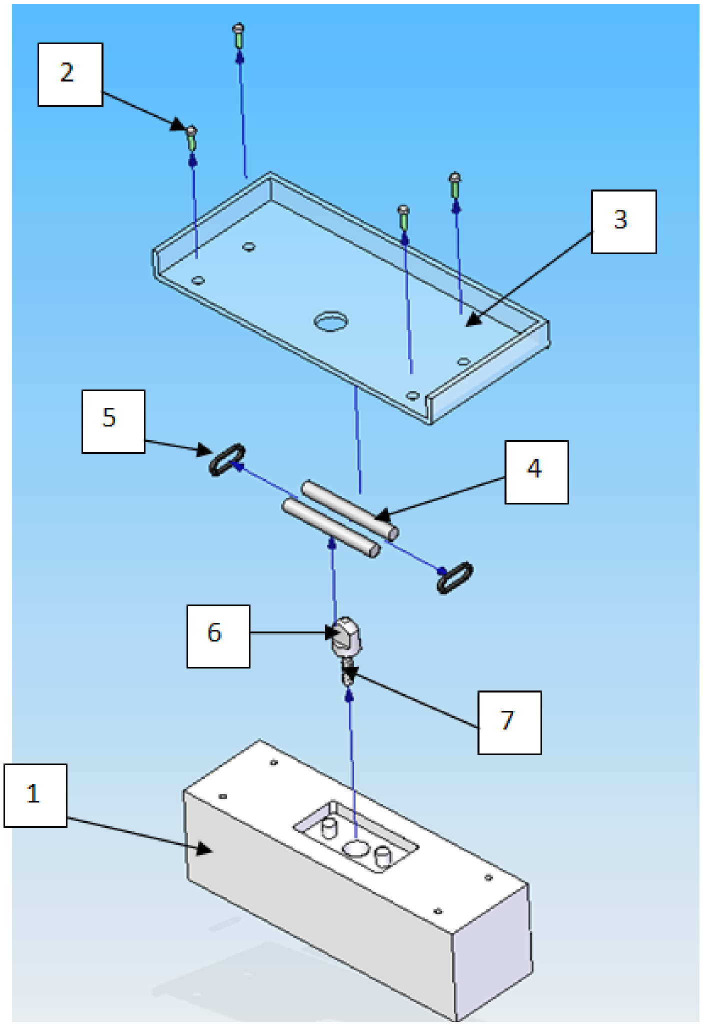

Figure 9.3.2.1. Medium O-ring Fixture

Table 9.3.2.1. Parts List for Medium O-ring Fixture

Part No.	Part	Material	Vendor
1	Base(1)	HPPE	
2	Screws(4)	10-24 x ½” Socket Head	Lowe’s
3	Top Plate(1)	Lexan	Athens Glass
4	Rods(2)	316 Stainless	
5	Elastic Bands(2)	Rubber	Lowe’s
6	Guide(1)	HDPE	
7	Spring(1)	Stainless Steel	Lowe’s

9.3.3 Small O-ring Fixture

The Parts List and Bill of Materials for the small O-ring fixture are given in **Table 9.3.3.1** and **Table 9.3.3.2**, respectively.

Table 9.3.3.1. Parts List

Item Number	Document Number	Part Name	Material	Quantity
1	T5-S-001	Base	12"x12"x1" HDPE	1
2	T5-S-003	Rubber	1/8" Natural Latex Rubber	1
3	T5-S-004	Top Cover	1/8" HDPE	1
4	T5-S-002	Front Cover	1/16" Stainless Steel	1
5		Screw	1"x1/8"Stainless Steel	2

Table 9.3.3.2. Bill of Materials

Material	Quantity	Cost	Supplier	Item #
12"x12"x1" HDPE	1	$22.69	McMaster-Carr	8619K491
12"x12"x1/8" Natural Latex Rubber	1	$25.80	McMaster-Carr	86395K22
12"x2"x1/16" Stainless Steel	1	$10.29	McMaster-Carr	9090K11
6-32 Brass Inserts	2	$2.68	Lowes	N/A
6-32 SS Screws	100	$5.37	Lowes	N/A

10.0 Conclusions

The objective of this project was to develop a system or device that would assist and increase production of installation of three different sixed O-rings onto three different parts with unique geometries. We determined to create three unique designs to assist with the installations of these three O-rings. Although some features are similar across designs, each of the three designs we generated are distinct. With reflection back to the Hierarchal Customer Needs List in **Table 2.2.2**, many of these needs were met with this design. Safety of the worker was a constant consideration with this project. All three devices are safe to use, although the Large O-ring fixture does have a couple of possible pinch points. However, we have deemed the risk of harm to be very small after operating the fixture ourselves and observing the customer operating it as well. All three fixtures are constructed with FDA compliant materials, making them sanitary and

easily washable. The simplistic operation of the fixtures is easy for workers to use. In fact, customer feedback indicates that the users enjoy using the fixture as it makes the workers more interested in their work.
The designs incorporate four basic steps for operation: place o-ring, orientate and place part, push part down to install O-ring, and remove part after installation is complete. These steps are easy to understand; the users could operate the devices correctly once they were shown how to do so and gained experience operating the devices.

The total cost is about $424 for one Large O-ring fixture, $287 for the Medium O-ring fixture, and $187 for the Small O-ring fixture. The Medium and Small O-ring fixtures met our target specification of less than $300. The cost for the large O-ring fixture exceeded our specifications.

The fixtures are small enough to fit into a sink and are small enough so that there is enough room on a table for several of them. Once assembled, the Large and Medium O-ring fixtures have only one required maintenance feature which is the occasional replacement of the rubber bands. The rubber bands will wear out after extensive use. The only required maintenance for the Small O-ring fixture is replacing the rubber layer when it wears out.

The main positive outcome for our designs for the Large O-ring fixture is that they reduce the amount the tactile handling of the parts. This was a problem for the workers due the rough edges of the parts wearing out the user's hands. The main negative of the design is that there is no automatic ejection of the part after the o-ring is installed. The users have difficulty removing the part with their hands. If an ejection was incorporated, the productivity and user friendliness would increase. At this point, the fixture does not increase user production time initially. Over time, the reduction in handling may improve worker production due to soreness in the hands from handling the part. OK

The Medium O-ring fixture, however, did increase the physical discomfort of users in certain circumstances. Users of the Medium O-ring fixture indicated that their hands would become sore after repeatedly operation. This problem could easily be solved if the users were given padded palm gloves when they operate the fixture. This is something which should be included with any of these fixtures manufactured in the future. Our customer feedback indicated, except for this problem, the customer was pleased with this fixture, though we do not know to date whether the customer would order more of this design.

We have concluded, based on customer feedback that the Small O-ring fixture did not successfully assist the users in installing O-rings. The users had difficulty in handling the small parts and O-rings which prevented them from correctly orienting the parts for installation. Thus, because of handling issues, we have determined that this design does not adequately address customer needs.

We conclude that these designs are not ready for production due to the incompleteness of the design. The customer feedback was essential in determining the capabilities and limitations that the user's encounter. Future work would involve the development of an ejection system and possibly reduce the overall manufacturing by combining parts. We determined that our target specifications do not adequately address the customer needs; therefore, any future work done on

this project should revisit and restate the customer needs. The reason we did not correctly address customer needs and expectations was that the customer had not begun their project until we had already begun prototype manufacturing and testing. Thus, our statement of needs and specifications was based on expected, not actual, customer needs and technical specifications.

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Appendix A. Data on Disabilities in the United States

Table A2. DISABILITY STATUS OF THE CIVILIAN NONINSTITUTIONALIZED POPULATION [4]

Age Group	Estimate	Margin of Error
Population 5 years and over	**273,835,465**	**+/-21,234**
With a disability	41,259,809	+/-98,726
Population 5 to 15 years	**44,696,789**	**+/-40,535**
With a disability	2,829,622	+/-32,313
Population 16 to 64 years	**193,568,216**	**+/-43,195**
With a disability	23,863,097	+/-85,217
Population 65 years and over	**35,570,460**	**+/-18,433**
With a disability	14,567,090	+/-42,335

Table A2. PERCENTAGE OF CIVILIAN NONINSTITUTIONALIZED POPULATION 21 TO 64 YEARS OLD WITH A DISABILITY BY STATE (STATES RANKED 1-30) [4]

Rank	State	Percent	Margin of Error
1	West Virginia	21.9	+/-0.7
2	Mississippi	20.5	+/-0.6
3	Kentucky	20.2	+/-0.5
4	Arkansas	20	+/-0.6
5	Alabama	18.6	+/-0.4
6	Oklahoma	18.1	+/-0.4
7	Maine	17.6	+/-0.7
8	Tennessee	17.4	+/-0.3
9	Louisiana	16.9	+/-0.4
10	South Carolina	15.8	+/-0.4
11	Montana	15.4	+/-0.8
12	North Carolina	15.1	+/-0.3
13	Alaska	15	+/-1.0
13	Missouri	15	+/-0.4
13	New Mexico	15	+/-0.7
16	Oregon	14.5	+/-0.5
17	Vermont	14.4	+/-0.8
18	Washington	14.3	+/-0.3
19	Ohio	14.2	+/-0.2
20	Michigan	14.1	+/-0.2
21	Wyoming	13.8	+/-1.1
22	Pennsylvania	13.7	+/-0.2
23	Idaho	13.4	+/-0.5
23	Indiana	13.4	+/-0.3
23	Rhode Island	13.4	+/-0.7
26	Delaware	13.3	+/-0.8
27	Georgia	13.1	+/-0.2
	United States	13	+/-0.1
28	Florida	13	+/-0.2
29	Texas	12.7	+/-0.2
30	Kansas	12.4	+/-0.4

Table A2. EMPLOYMENT STATUS OF CIVILIAN NONINSTITUTIONALIZED POPULATION 16 TO 64 YEARS OLD WITH A DISABILITY [4]

EMPLOYMENT STATUS	Total	Margin of Error	Male	Margin of Error	Female	Margin of Error
Population 16 to 64 years	**193,568,216**	**+/-43,195**	**95,522,006**	**+/-31,456**	**98,046,210**	**+/-31,266**
With any disability	23,863,097	+/-85,217	11,750,311	+/-54,860	12,112,786	+/-52,673
Employed	37.2%	+/-0.1	40.2%	+/-0.2	34.2%	+/-0.2
With a sensory disability	5,422,873	+/-43,111	3,081,424	+/-30,448	2,341,449	+/-25,740
Employed	46.5%	+/-0.4	51.4%	+/-0.5	40.1%	+/-0.5
With a physical disability	14,130,458	+/-64,614	6,518,468	+/-40,648	7,611,990	+/-40,381
Employed	31.7%	+/-0.2	32.9%	+/-0.3	30.6%	+/-0.3
With a mental disability	9,234,123	+/-52,168	4,659,370	+/-28,646	4,574,753	+/-36,550
Employed	28.4%	+/-0.3	30.2%	+/-0.4	26.4%	+/-0.3
With a self-care disability	4,187,492	+/-32,408	1,924,005	+/-20,734	2,263,487	+/-23,620
Employed	16.9%	+/-0.3	17.7%	+/-0.4	16.3%	+/-0.4
With a go-outside-home disability	6,215,391	+/-37,742	2,781,937	+/-26,077	3,433,454	+/-27,290
Employed	17.1%	+/-0.2	18.4%	+/-0.3	16.0%	+/-0.3
With an employment disability	13,667,248	+/-62,469	6,605,969	+/-39,163	7,061,279	+/-40,255
Employed	17.6%	+/-0.2	18.9%	+/-0.3	16.3%	+/-0.2
No disability	169,705,119	+/-103,137	83,771,695	+/-62,741	85,933,424	+/-61,943
Employed	75.1%	+/-0.1	81.1%	+/-0.1	69.2%	+/-0.1

Table A3. MEDIAN EARNINGS BY DISABILITY STATUS BY SEX FOR THE CIVILIAN NONINSTITUTIONALIZED POPULATION 16 YEARS AND OVER WITH EARNINGS [4]

	Estimate	Margin of Error
Total:	27,329	+/-37
With a disability:	17,720	+/-135
Male:	21,441	+/-154
Female:	14,495	+/-138
No disability	28,425	+/-64
Male:	34,294	+/-107
Female:	22,747	+/-62

Appendix B. Customer Observation Notes

Observation Notes from Initial Meeting with SW Resources **Date: Sept. 18, 2008**
Brent Morris and Jonathan Robe met with Kellie Conrad to discuss possibly working with SW Resources for the Senior Design project. We toured the facilities of SW Resources to observe the different project opportunities that we would have if we selected them to be our customer. The different projects which Kellie listed as options for us to consider are the following: 1. Widget Project with DuPont (assembling a fountain drink machine syrup dispenser with O-rings. 2. Installing Braille beads onto room signs (inserting the Braille beads into drilled holes in the sign). 3. letter folding department (folding letters and inserting them into envelopes). SW does have a paper folding machine which they already use for this. 4. bagging nails and screws (they will be getting a machine soon to do most of this task).

Observation Notes from Meeting with SW Resources
Date: October 8, 2008

We visited SW Resources with the goal of meeting and observing some of the employees who will be participating in the O-ring assembly project.

The information that we gathered from our visit included:

- all parts (including the 3 different sized O-rings) were in separate bags (all of the parts were loose inside each bag)
- electric outlets were available in the workspace
- large tables (4 ft x 10 ft) with chairs were in the workspace. Some tables were plastic.
- According to SW managers, the assembly of each O-ring was to occur at different tables. The parts with the O-rings applied were to be deposited into part bins which were to be taken to a separate station for final product assembly.
- The device must be sanitary and be disinfected once a day.
- The project manager or supervisors are going to supply the parts (including the O-rings) to the workers.
- Each ring assembly will likely be color coded.
- The fixture is to fit in the kitchen sink (15 in. x 15 in.)
- About 80 workers total will be working on the project.
- They will assemble 4 million parts the first year, with roughly 200,000 parts per year after that first year.
- The part bins will be color coded then weighed to get the number of parts each worker has assembled.
- Workers are paid based on their part output.
- Observations of employees current performance:

    Employee 1: Severe mental disability, with some physical disability
    Averaged 1 size M o-ring every 15 seconds

    Employee 2: Moderate mental disability, no physical disability
    Averaged 1 size L o-ring every 6 seconds

Appendix C. FMEA Worksheets

Failure Modes and Effects Analysis for Safe, Reliable, Effective Designs

Step1:

Provide a description of the full system including all subsystems and accessories in all modes of operation (including storage, setup, transportation, operation, cleaning, maintenance, etc.). If possible please include sketches with users in operating positions for the main operating modes. This information can be included here or as an attachment to this document.

Modes of operation: Storage, setup, transportation, operation, and cleaning

Step 2:
Identify all potential failures and safety hazards for the system in each mode of operation. A failure is any undesirable occurrence associated with the system. If multiple failure modes have a common root cause, please compile them together and identify the root cause.

1. O-ring is not completely installed
2. Fracture of the o-ring
3. Fatigue in the rubber sheet
4. Material wear (corrosion) due to cleaning
5. Safety risks due to sharp edges in metal feed tray
6. Bending in metal o-ring feed tray
7. Stripping of threads in plastic base
8. Fracture of fixture if it is dropped

Step 3:

For **all significant potential failure modes** in step 2, complete an FMEA table to determine the type of action necessary to achieve acceptable risk level, and the priority of the action compared to the other failure modes.

Potential Failure 1 – *O-ring is not completely installed*

Operating mode when failure could occur	***Potential Failure Mode***	
Operation	*Text here*	
	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	7	**5**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	6	3
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	9	6
Risk Priority Number (RPN=SEV*OCC*DET)	378	90

1. Include some discussion/justification for the rating for **severity** (SEV)

When the o-ring is not installed properly, this means that the worker must repeat the procedure in order to install the o-ring. But no harm is done to the user. If the devices consistently do not install the o-rings, then the device is practically inoperable.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

Our first prototypes and mockups were inconsistent in their performance. However, later on in the design process, they were much better.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

It would be fairly easy for the workers to detect whether or not the o-ring was successfully installed. This procedure would be no different than the procedure they currently use for the hand installation.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Refine the designs to reduce the required input force. This appears to be a major cause for this type of failure.

5. Notes on **Completed Actions**:

Potential Failure 2 – *Fracture of the o-ring*

Operating mode when failure could occur	***Potential Failure Mode***	
Operation	*Text here*	
	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	6	**6**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	2	1
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	7	7
Risk Priority Number (RPN=SEV*OCC*DET)	84	42

1. Include some discussion/justification for the rating for **severity** (SEV)

> Fracture of the o-ring would render the product unusable and would incur material cost to the customer, but no one would be harmed by this failure.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

> We do not think this failure is likely since no sharp edges are incorporated in the design which could cause the o-ring to fracture.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

> It would be easy for a worker without disability to detect this failure, but we are not sure if any of the employees with disabilities would necessary be able to consistently detect this failure mode.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

> We will perform FEA on the o-ring to determine if normal operating conditions would cause this type of failure.

5. Notes on **Completed Actions**:

Potential Failure 3 – *Fatigue in the rubber sheet*

Operating mode when failure could occur	***Potential Failure Mode***	
Operation, cleaning, transportation	*Text here*	
	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**8**	**3**
Potential Cause(s) / Mechanism(s) of Failure	3	3

(Probability of occurrence, OCC)		
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	4	3
Risk Priority Number (RPN=SEV*OCC*DET)	96	27

1. Include some discussion/justification for the rating for **severity** (SEV)

If the rubber layer fails due to fatigue, the device really is not very operable, at least at desired performance levels, but the user is not harmed in any way.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

Final value for occurrence is based on FEA analysis for fatigue failure.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

It would be fairly easy to detect fatigue failure in the rubber. As the material wears down, its performance would gradually reduce. The rubber layer will not catastrophically fail in a very dangerous manner.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Perform a finite element analysis on the rubber layer to determine if the rubber material is robust enough to last for the desired length of time. Find desired time and load on an S-N curve for rubber.

5. Notes on **Completed Actions**:

We have designed the small o-ring fixture so that the rubber layer can be replaced easily and simply were the rubber layer to fail due to fatigue. However

Potential Failure 4 – *Material wear (corrosion) due to cleaning*

Operating mode when failure could occur	***Potential Failure Mode***	
Setup, operation, transportation, cleaning		
	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**7**	**5**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	2	2
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	2	2
Risk Priority Number (RPN=SEV*OCC*DET)	28	20

1. Include some discussion/justification for the rating for **severity** (SEV)

If the rubber corrodes than the fixture is no longer useful and the rubber must be replaced. While there are no safety issues here it does render the fixture useless which is unacceptable.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

The Buna/N rubber is FDA approved for corrosion resistance

3. Include some discussion/justification for the rating for probability of **detection** (DET)

Not necessary

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

The risk is fairly low for this mode of failure. The only option to reduce the risk is to find a better grade of rubber or an alternative design not requiring rubber

5. Notes on **Completed Actions**:

We used only FDA compliant materials for our devices, so all materials were designed to be able to withstand basic sanitary operations.

Potential Failure 5 – *Safety risks due to sharp edges*

Operating mode when failure could occur	***Potential Failure Mode***	
Setup, transportation, storage, operation, cleaning		
	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	9	**9**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	3	1
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	1	1
Risk Priority Number (RPN=SEV*OCC*DET)	27	9

1. Include some discussion/justification for the rating for **severity** (SEV)

If there is a sharp edge or pinch point then it is a serious safety issue.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

This should not occur as long as we double check and make sure all edges are rounded and no pinch points exist

3. Include some discussion/justification for the rating for probability of **detection** (DET)

Not necessary

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Round all edges and keep pinch points to a minimum. This is not much of a problem due to the simplicity of the design for the small and medium o-rings.

5. Notes on **Completed Actions**:

After prototype construction, all edges were rounded. Thus, we had no sharp corners or edges in our fixtures that would endanger the users.

Potential Failure 6 – *Bending in metal o-ring feed tray*

Operating mode when failure could occur	***Potential Failure Mode***	
Operation, storage, setup, transportation, cleaning	*Bending and deflection of the metal*	
	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	7	**0**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	7	0
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	2	0
Risk Priority Number (RPN=SEV*OCC*DET)	98	0

1. Include some discussion/justification for the rating for **severity** (SEV)

If the tray is bent out of shape, then feeding the o-rings onto the fixture will, perhaps, be more difficult but this is not critical to the design. Of more concern would be bending in the legs which support the tray. If the legs are the location of failure, then it is possible that the fixture will not operate according to design.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

If we make the tray out of sheet metal, then only relatively large loads would cause major deflection or bending in the fixture. This would most likely happen during transportation or maintenance of the fixture than during the normal operation or setup.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

It will be relatively easy to detect deflection or bending in the metal feed tray.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Design the fixture to have a substantially larger top surface area so that we can eliminate the metal feed tray

5. Notes on **Completed Actions**:

Our updated design has eliminated the need for the metal feed tray for the small o-ring fixture. The device will be roughly 1’ x 1’ with short, vertical walls on the top surface to contain the o-ring during operation

Potential Failure 7 – *Stripping of internal threads in plastic base*

Operating mode when failure could occur	***Potential Failure Mode***	
Setup, maintenance, cleaning	*Failure due to thread* stripping of the internally threaded member	
	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**8**	**0**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	3	0
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	6	0
Risk Priority Number (RPN=SEV*OCC*DET)	144	0

1. Include some discussion/justification for the rating for **severity** (SEV)

If stripping of the internal threads in the plastic base does indeed occur, then the top plastic and rubber layers (as well as the feed tray) will no longer be firmly attached to the base. The entire fixture will likely become unusable because the layers will not be held in place as is required by the design.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

It is more likely that thread stripping will occur in the plastic base than in the screw threads. Depending upon the quality of plastic, thread stripping may be very likely in the plastic base.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

It will be fairly easy to detect this failure mode. As the threads are stripped over time, the problem will be noticed whenever the fixture is disassembled for maintenance.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

Eliminate any need for bolts and bolt holes in the plastic base

5. Notes on **Completed Actions**:

Our updated design for the small o-ring fixture has eliminated any need for bolt holes. Thus, we will not have any threaded holes in the plastic base or even in the top plastic layer.

Potential Failure 8 – *Fracture of fixture if dropped*

Operating mode when failure could occur	*Potential Failure Mode*	
Transportation, operation		
	Initial Evaluation	***After Action Results***
Potential Effect of Failure (Severity, SEV)	**10**	**5**
Potential Cause(s) / Mechanism(s) of Failure (Probability of occurrence, OCC)	7	7
Current Controls for Detection and Prevention (Probability that failure is detected and prevented, DET)	1	1
Risk Priority Number (RPN=SEV*OCC*DET)	70	35

1. Include some discussion/justification for the rating for **severity** (SEV)

If the fixture were to fracture upon dropping, it would render the device inoperable; however, the user would not likely be harmed. Therefore, we dropped the severity from 10 to 5.

2. Include some discussion/justification for the rating for probability of **occurrence** (OCC)

Potentially, there are many causes which could lead to the devices being dropped during operation. The user may accidentally bump the devices on the table on which they rest causing them to fall to the floor. Also, since the devices need to be cleaned on a daily basis, the workers responsible for cleaning the devices could drop them during the cleaning process. This would be easy to do when the devices were still wet or slippery.

3. Include some discussion/justification for the rating for probability of **detection** (DET)

Whether or not the device failed due to this mode would be easy to verify for any user, even those with severe physical and moderate mental disabilities.

4. **Recommended actions** to achieve acceptable risk: Make specific recommendations for action and include some discussion of the alternatives that were considered, the person(s) responsible for completing the actions, and the completion date.

We will investigate the robustness of these designs using FEA to simulate this design failure. We also verified this test physically when we accidentally dropped one of these devices during transportation.

5. Notes on **Completed Actions**:

The FEA results indicate that it is not likely that this failure mode will occur. The HDPE base is strong enough to resist this type of failure.

Appendix D. Customer Prototype Evaluation Form

CUSTOMER PROTOTYPE EVALUATION FORM: STEM O-RING FIXTURE

Mechanical Masters
Department of Mechanical Engineering
Ohio University

Circle one for each. 1: Strongly Disagree, 2: Disagree, 3: Neutral, 4: Agree, 5: Strongly Agree

User Friendly:	1	2	3	4	5
Sufficient Size:	1	2	3	4	5
Operates Consistently:	1	2	3	4	5
Increases Productivity:	1	2	3	4	5
Safe for Employees:	1	2	3	4	5
Easy to Clean:	1	2	3	4	5

Overall, does this design adequately meet your needs? Explain.

Specifically, what were the problems, if any, with this device?

Do you feel that you would use this device in the future? Explain.

How could the design for this device be improved?

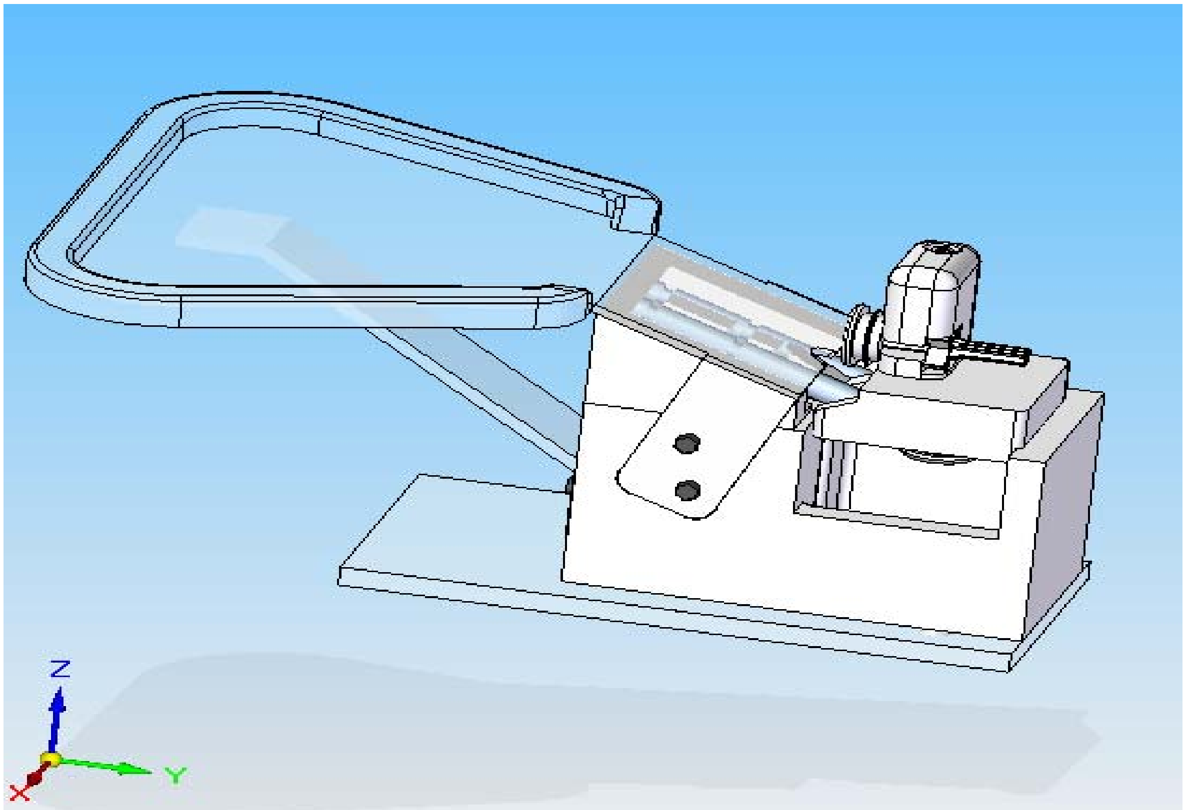
Additional comments:

Appendix E. User's Manual

QCD-ENCORE

O-ring Installation Fixture
User Manual

Chapter 1: Large O-ring Fixture (Stem)



1.1 Warnings and Safety Precautions

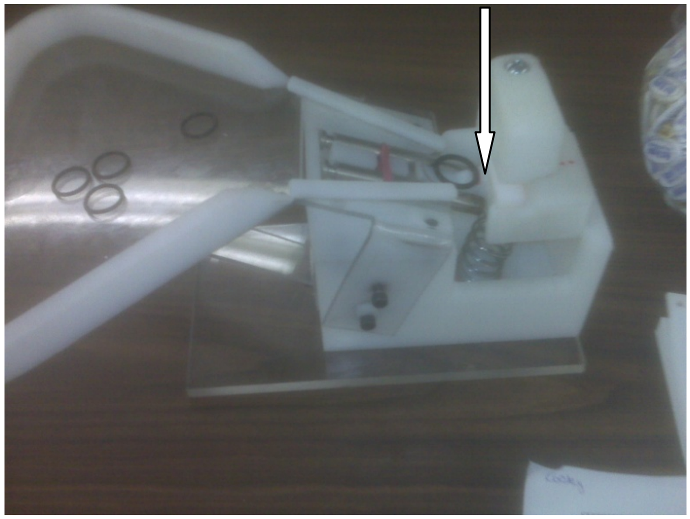
⚠ Dropping fixture from large height(s) may result in damage to the fixture.

⚠ Keep fingers above stem platform, to avoid pinch points.

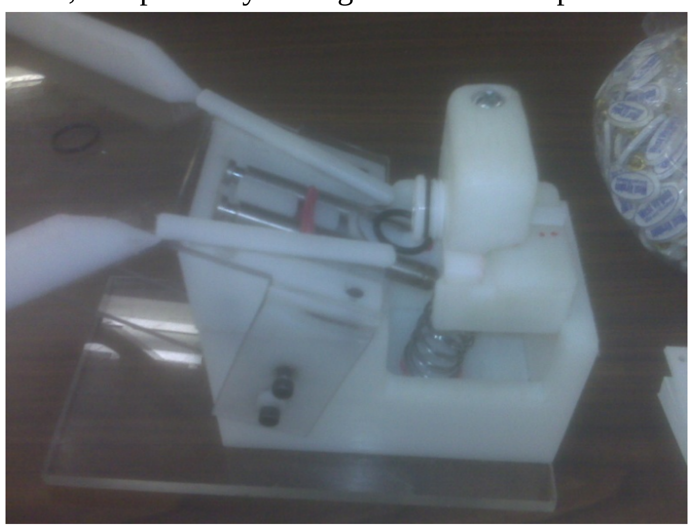
1.2 Operating Instructions

1. Place o-rings and/or stems, onto the tray.

2. Employee slides an o-ring down the slide, until the o-ring sits into the groove marked with red.

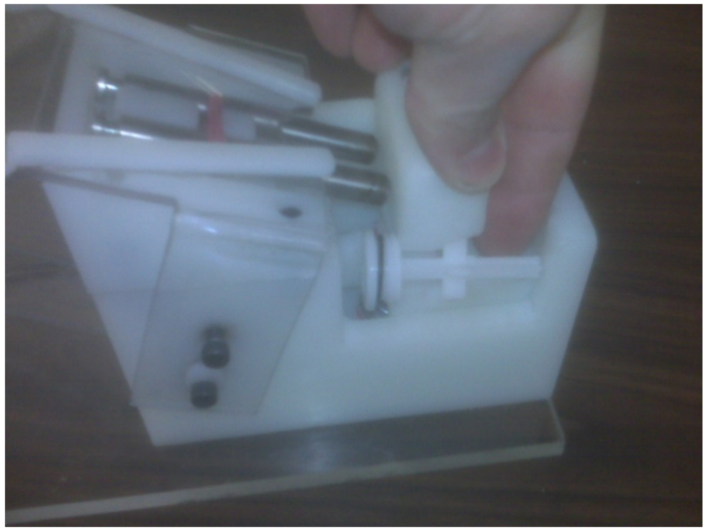


3. Load the device; completed by sliding a stem into the part holder, as shown.



4. The employee then pushes straight down on the stem holder, allowing the stem to slide through the rods, applying the o-ring.

5. While holding the knob down, the stem is removed by using a finger and sliding it out of the holder.



1.3 Suggested Maintenance Schedule and Instructions

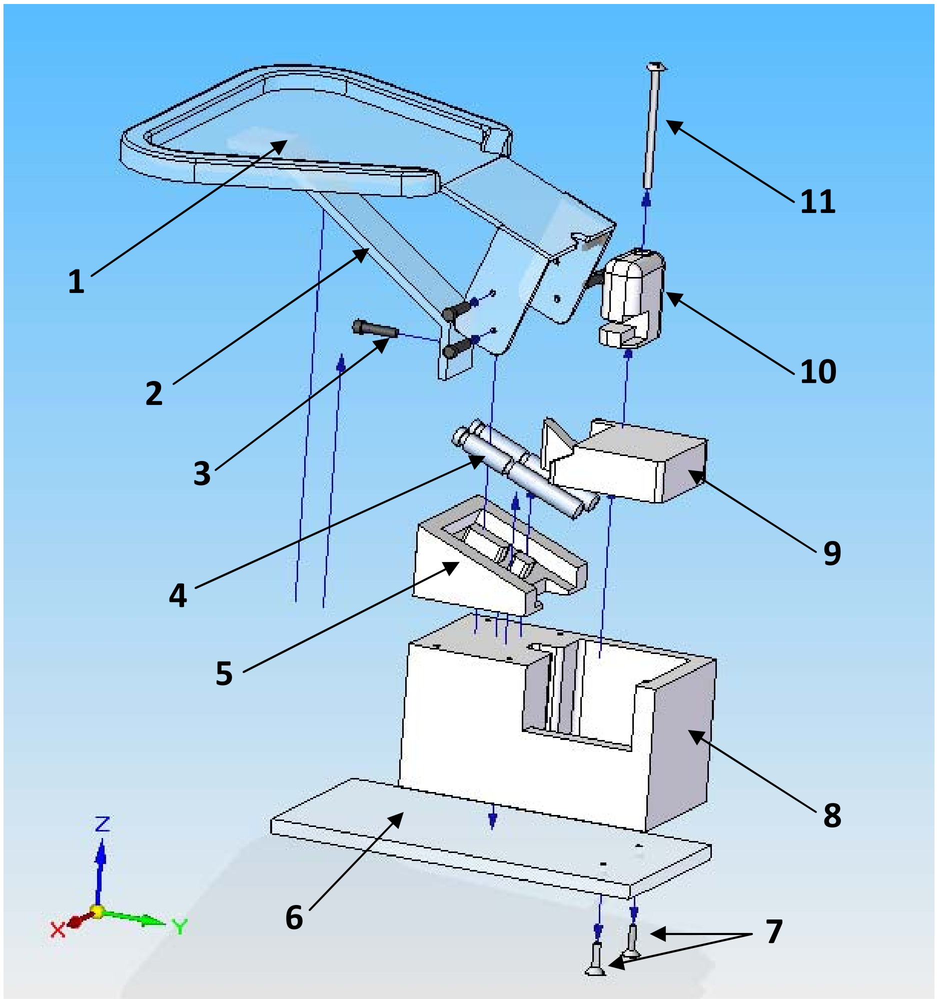
A. Replacing the rubber bands.

1. Use a 5/32" Allen Key wrench to loosen the tray and tray brace, 5 bolts.
2. Remove rods (2) from base.
3. Remove rubber bands from rods, and install new bands.
4. Replace the rods back into position, and reinstall the tray, and mounting bolts.

1.4 Troubleshooting and Service Instructions

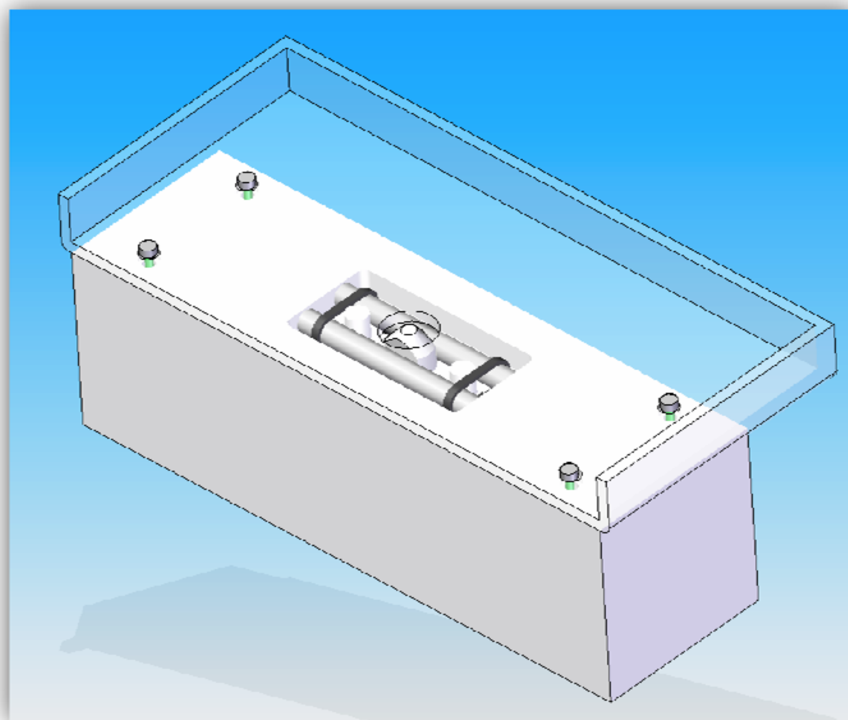
1. If the fixture is not functioning properly, try replacing the rubberbands first.
2. Or check to see that the tray cutout, for the o-ring, is relatively centered on the two rods, and the neck of the platform.

1.5 Replacement Parts Information


1
2
3
4
5
6
7
8
9
10
11
Z
X
Y

Part Number	Part	Material	Vendor
1	Tray	Lexan & HDPE rails	McMaster Carr/Athens Glass
2	Tray Brace	Lexan	Athens Glass
3	8-32 x 1” Hex Bolt : (5)		Lowes
4	316 SS $\frac{3}{8}$ in. rods	316 SS	McMaster Carr
5	Rod Holder	HDPE	McMaster Carr
6	Base	$\frac{3}{8}$ in. Plexi-Glass	McMaster Carr
7	Base Screws	1” coarse thread screws	Lowes
8	Box	HDPE	McMaster Carr
9	Platform	HDPE	McMaster Carr
10	Stem Holder	HDPE	McMaster Carr
11	Long Screw	$2\frac{1}{2}$ in. machine screw & nut	Lowes

Chapter 2: Medium O-ring Fixture (Body)



2.1 Warnings and Safety Precautions

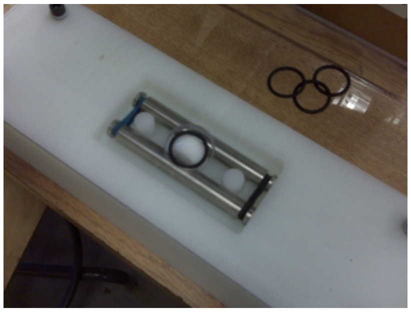
WARNING: Dropping fixture from large height(s) may result in damage to the fixture.

WARNING: Do not place fingers in hole in top cover.

2.2 Operating Instructions

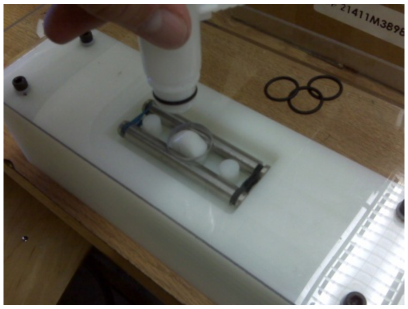
6. Place o-rings on top cover to be assembled.

7. Place 1 o-ring over guide.



8. Place the part (vertical orientation) on top of the o-ring and push down on the part until it travels through the rods, securing the o-ring on the part.

9. Pull part out



10. Repeat steps 1-4 for desired part quota.

2.3 Suggested Maintenance Schedule and Instructions

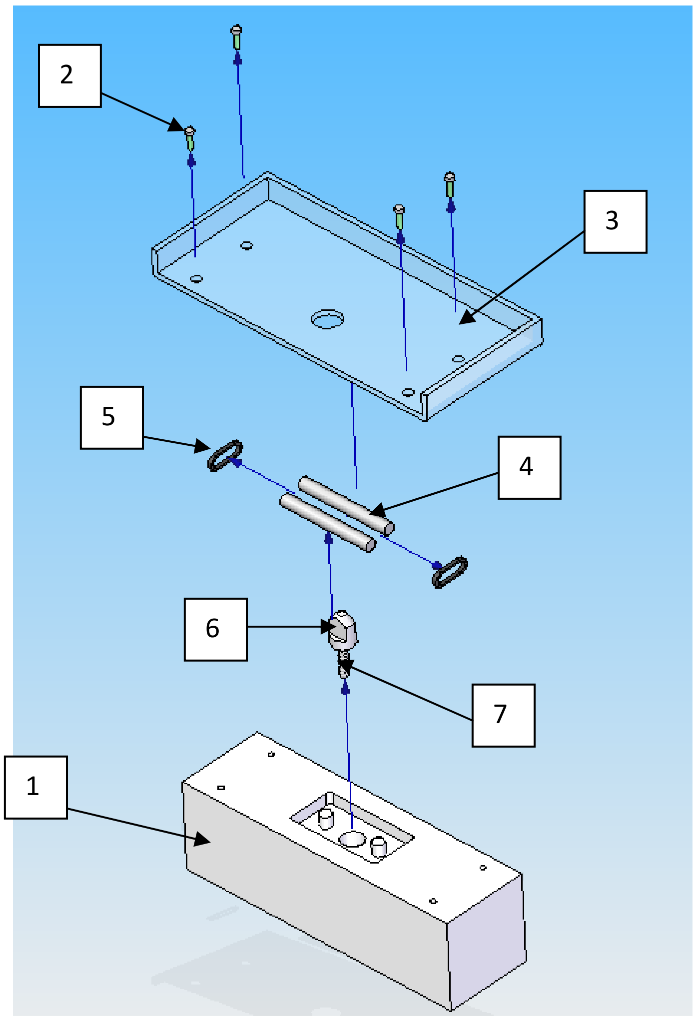
A. Replacing the rubber bands.

5. Use a 5/32” Allen Key wrench to loosen the bolts (4) and remove the top cover.
6. Remove rods (2) from base.
7. Remove rubber bands from rods.
8. Install new rubber bands on rods and assemble fixture.

2.4 Troubleshooting and Service Instructions

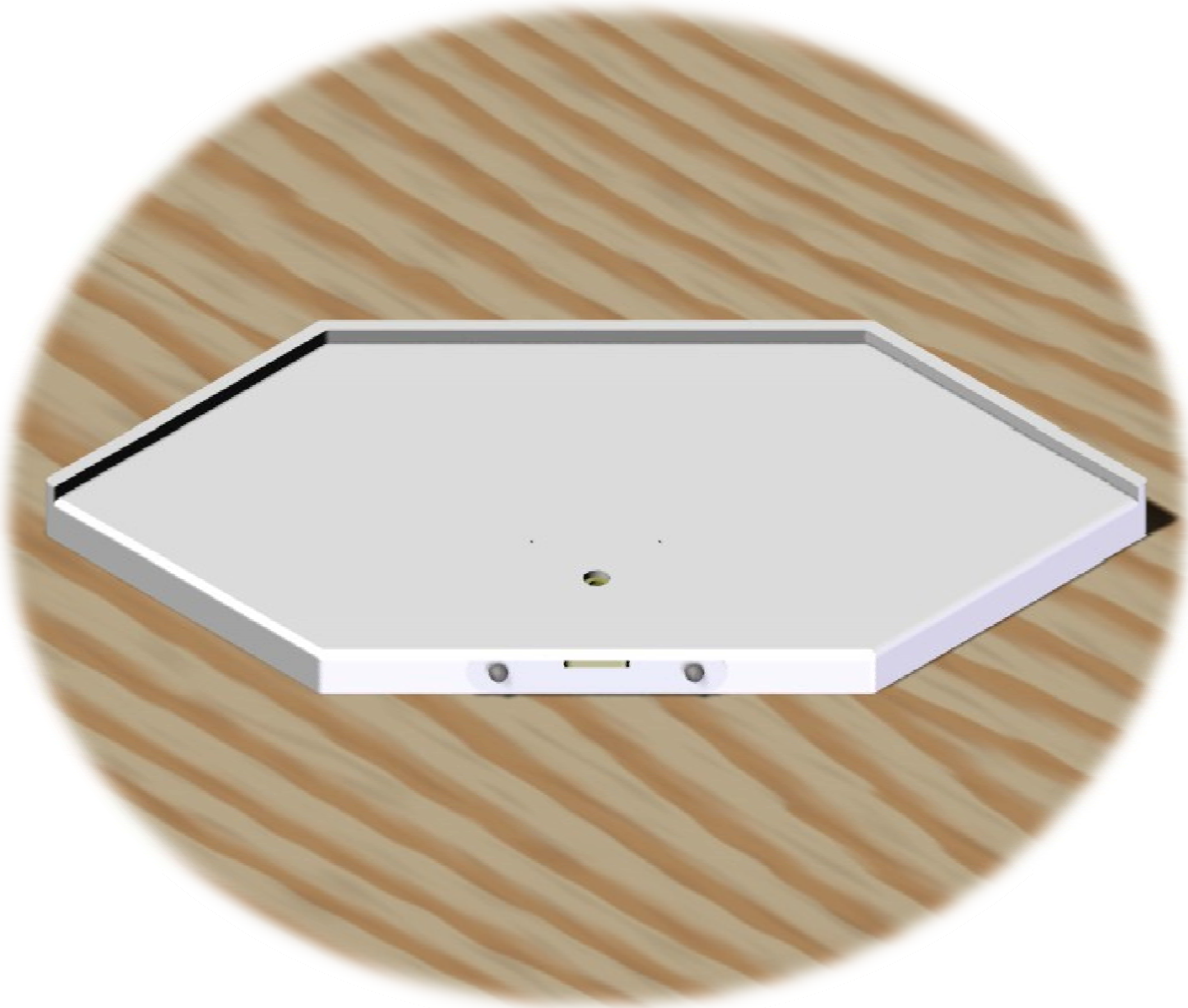
If the fixture is not functioning properly, try replacing the rubber bands.

2.5 Replacement Parts Information



Part No.	Part	Material	Vendor
1	Base(1)	HPPE	
2	Screws(4)	10-24 x ½” Socket Head	Lowe’s
3	Top Plate(1)	Lexan	Athens Glass
4	Rods(2)	316 Stainless	
5	Elastic Bands(2)	Rubber	Lowe’s
6	Guide(1)	HDPE	
7	Spring(1)	Stainless Steel	Lowe’s

Chapter 3: Small O-ring Fixture (Tip)



3.1 Warnings and Safety Precautions

WARNING: Do not use this device in any manner inconsistent with the operating instructions given below.

WARNING: Do not use any tool other than a screw-driver to perform maintenance or troubleshooting. Use of any other tool could damage the device.

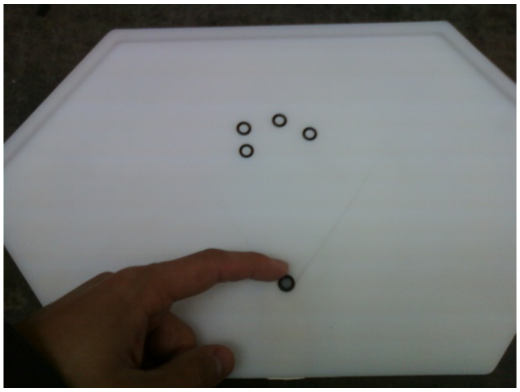
WARNING: Do not use this device to install o-rings with an outside diameter greater than 0.375 inches or less than 0.25 inches.

3.2 Operating Instructions

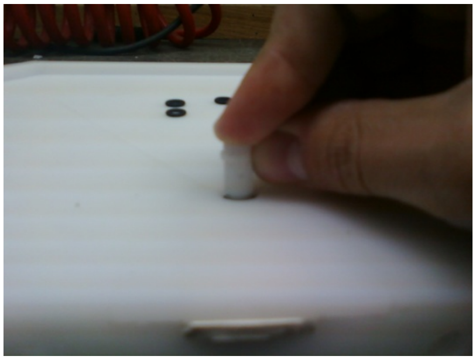
Follow these steps to install the small o-ring onto the small, tip part of the QCD Encore assembly:

1) Deposit bag of small o-rings onto top surface of the device

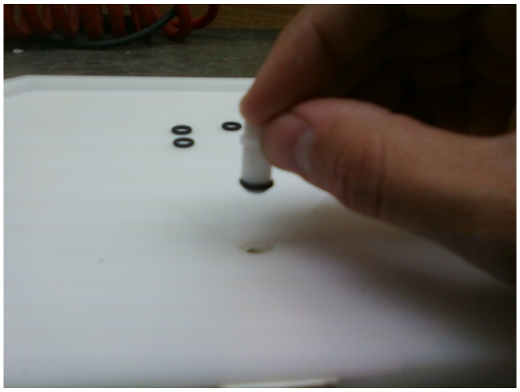
2) Slide one (1) o-ring into the hole. The o-ring will now lie on the top surface of the rubber layer which is in the base.



3) Pick up one (1) plastic tip part. Verify that the part is inverted.
4) Insert the plastic tip part into the hole on the top surface of the device.
5) Press the plastic tip part into the rubber layer until the o-ring has rolled onto the tip part.



6) Remove the tip part from the device and verify that the o-ring was installed correctly.



7) Repeat steps 1) through 6)

3.3 Suggested Maintenance Schedule and Instructions

Periodically, the rubber layer will wear out and will need to be replaced. The following procedure describes how the rubber layer should be replaced:

1) Completely loosen the screws which hold the front cover.
2) Remove the front cover from the device.
3) Slide the rubber layer out of the pocket
4) Slide the new rubber layer into the pocket
5) Replace the cover and tighten the screws which hold the cover

We recommend replacing the rubber layer every three (3) months or as needed. Extended use of the device will mean the rubber layer will need to be replaced more frequently.

Since this device is designed to assist with installation of o-rings for use in a food related use, the device should be cleaned daily to ensure that it meets sanitation requirements. To clean the device, either spray it with disinfectant or wash it with soap and water in a sink. The device does not need to be disassembled for the sanitation procedure. After the device is washed, dry the hole in the device to ensure that no water is left sitting in the hole.

3.4 Troubleshooting and Service Instructions

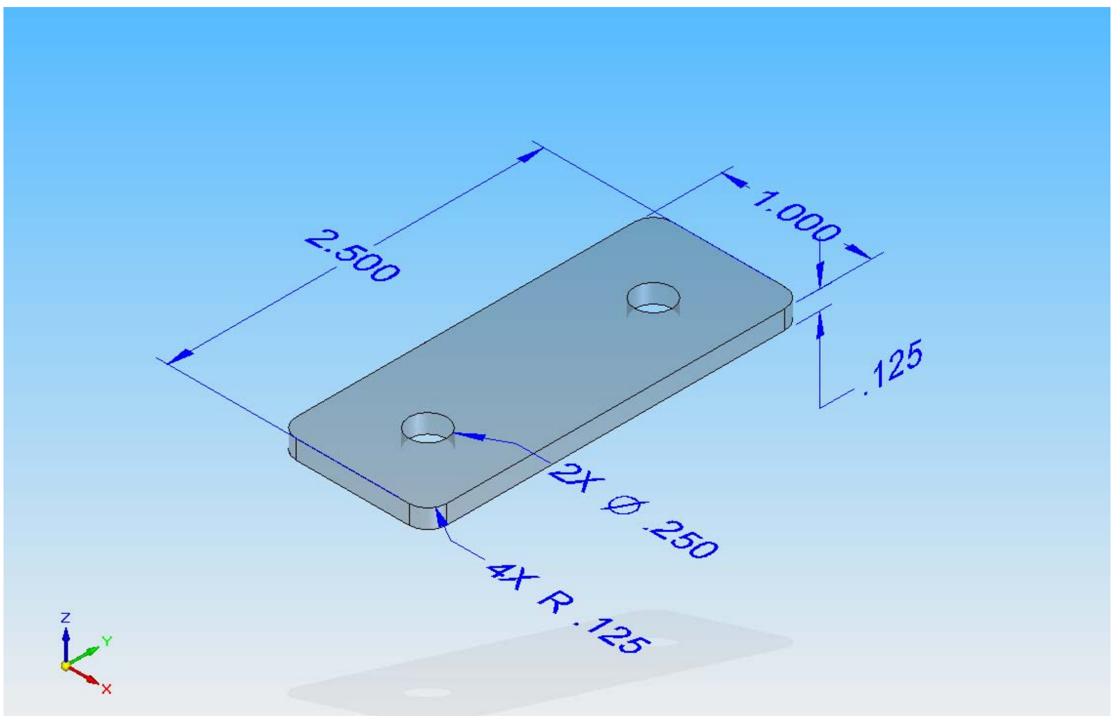
If this device does not correctly install o-rings, replace the rubber layer.

3.5 Replacement Parts Information

Small O-Ring Fixture Parts List		
Part	**Quantity**	**Material**
Base	1	12”x12”x1” HDPE
Rubber Sheet	1	.125” Natural Latex

		Rubber
Top Cover	1	.125” HDPE
Front Cover	1	.0625” Steel
Screw	2	#10-32 .625”

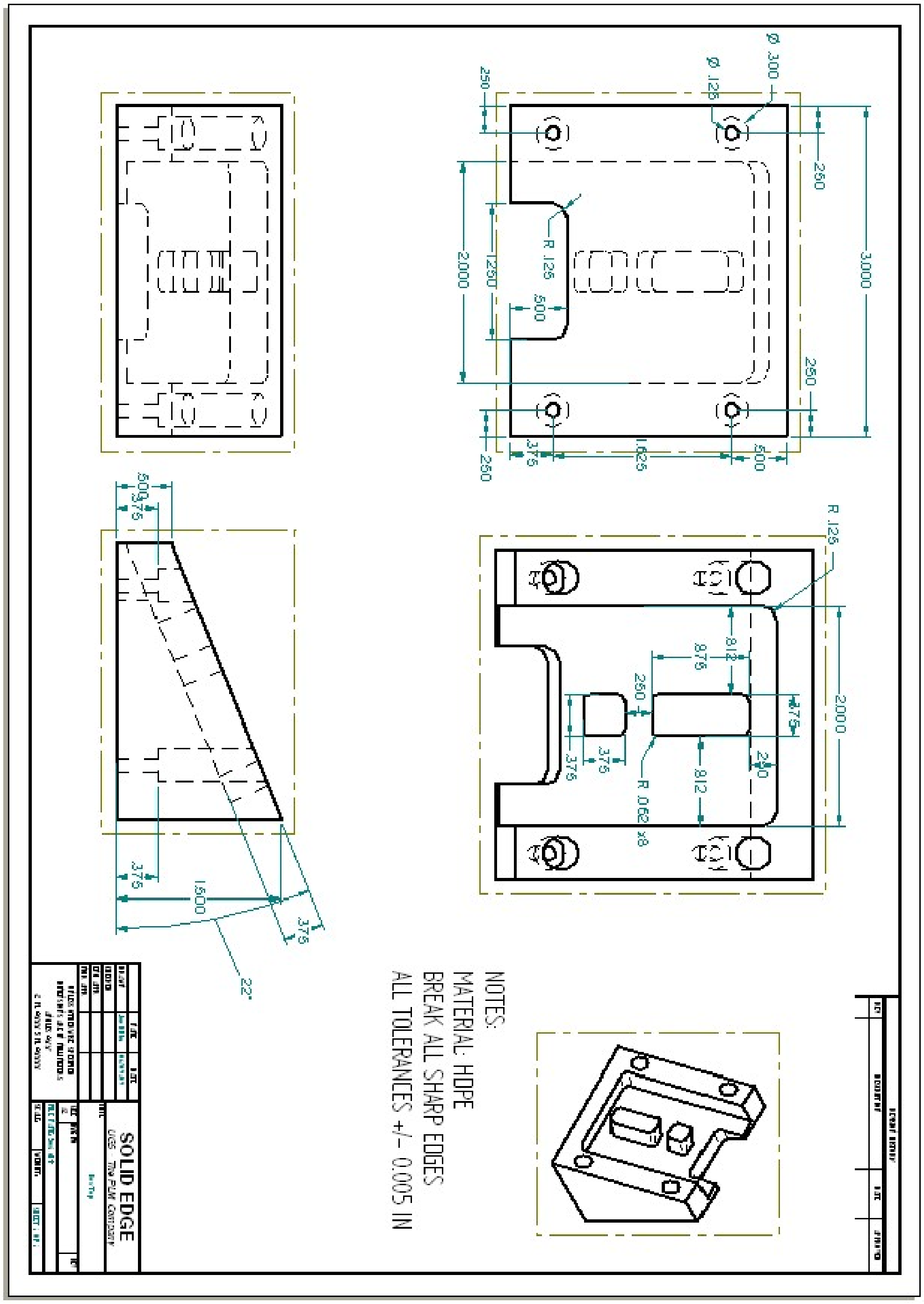
The rubber sheet is the only part of the fixture that will need to be replaced. Each sheet of rubber will have two holes punched in it so that when the first hole wears out it can be flipped and the second hole can be used. Once the second hole wears out it must be replaced with a new part. Several extra parts will be provided initially. Should more be needed, 12”x12”x.125” sheets can be ordered from McMaster Carr at http://www.mcmaster.300%) com/#rubber-and-foam-rubber/=1h0dpc. The part will need to be cut using a sharp pair of shears and a .25” hole punch. The dimensions are given in the figure below. OK

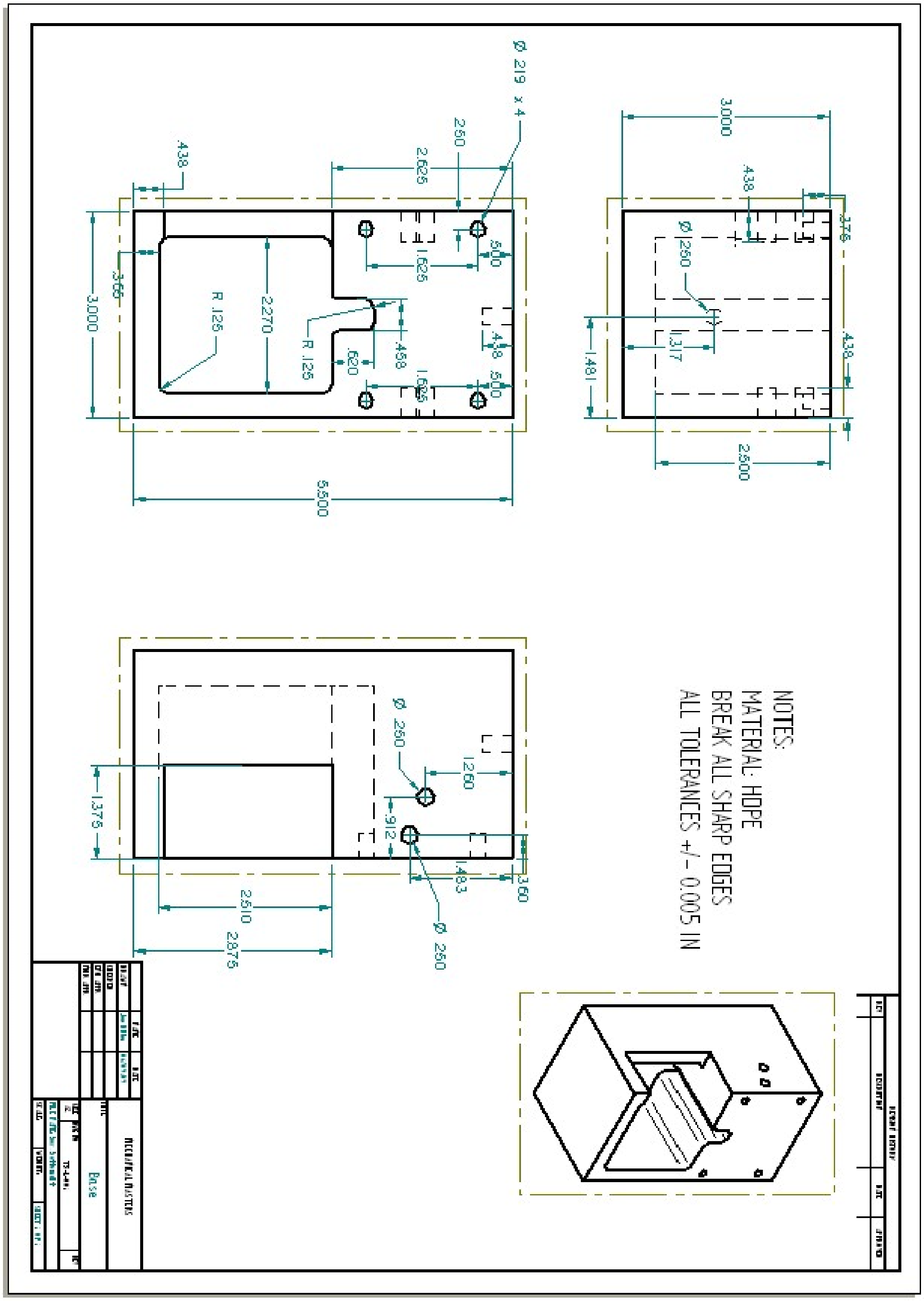


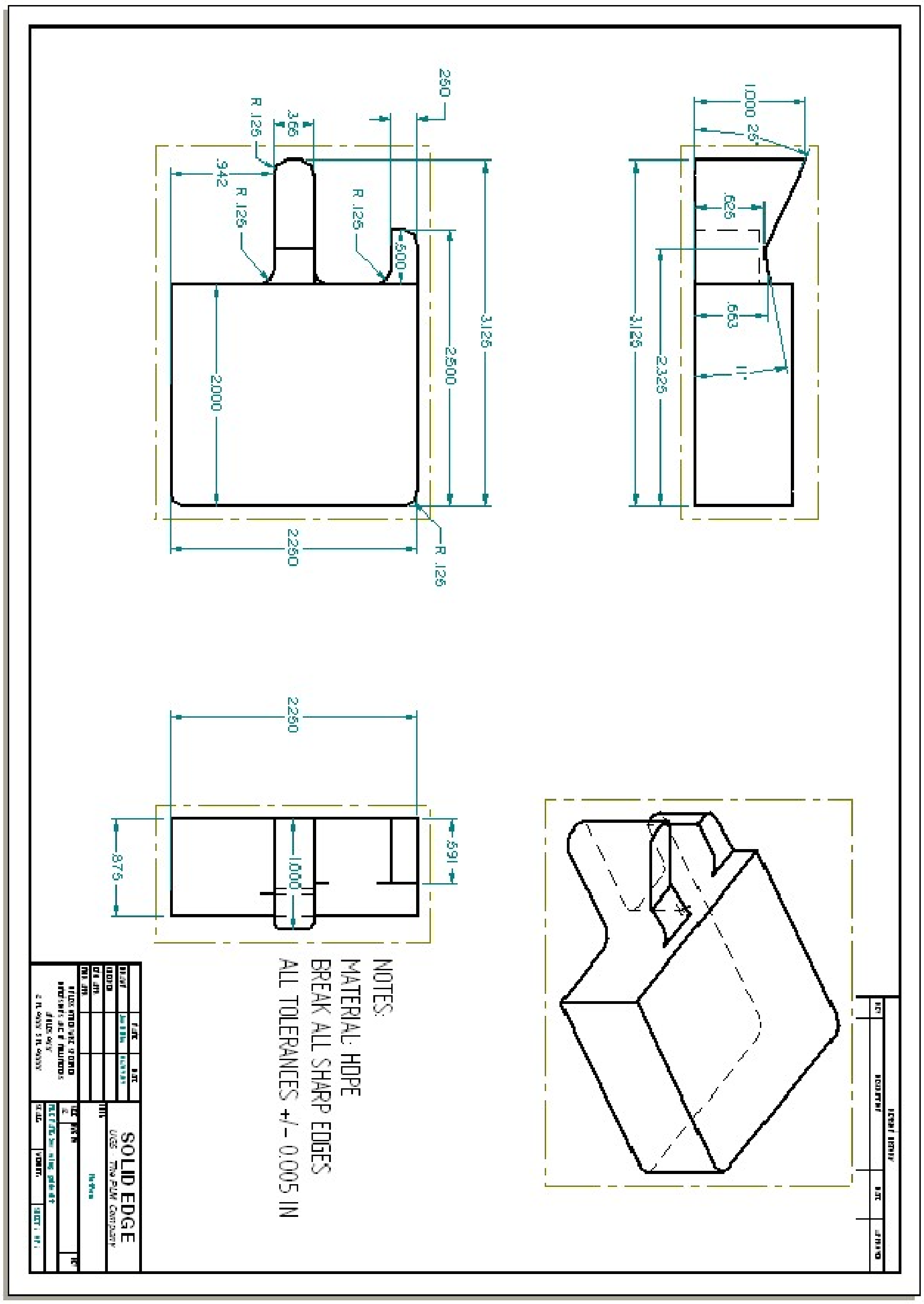
Properties of Natural Latex Rubber

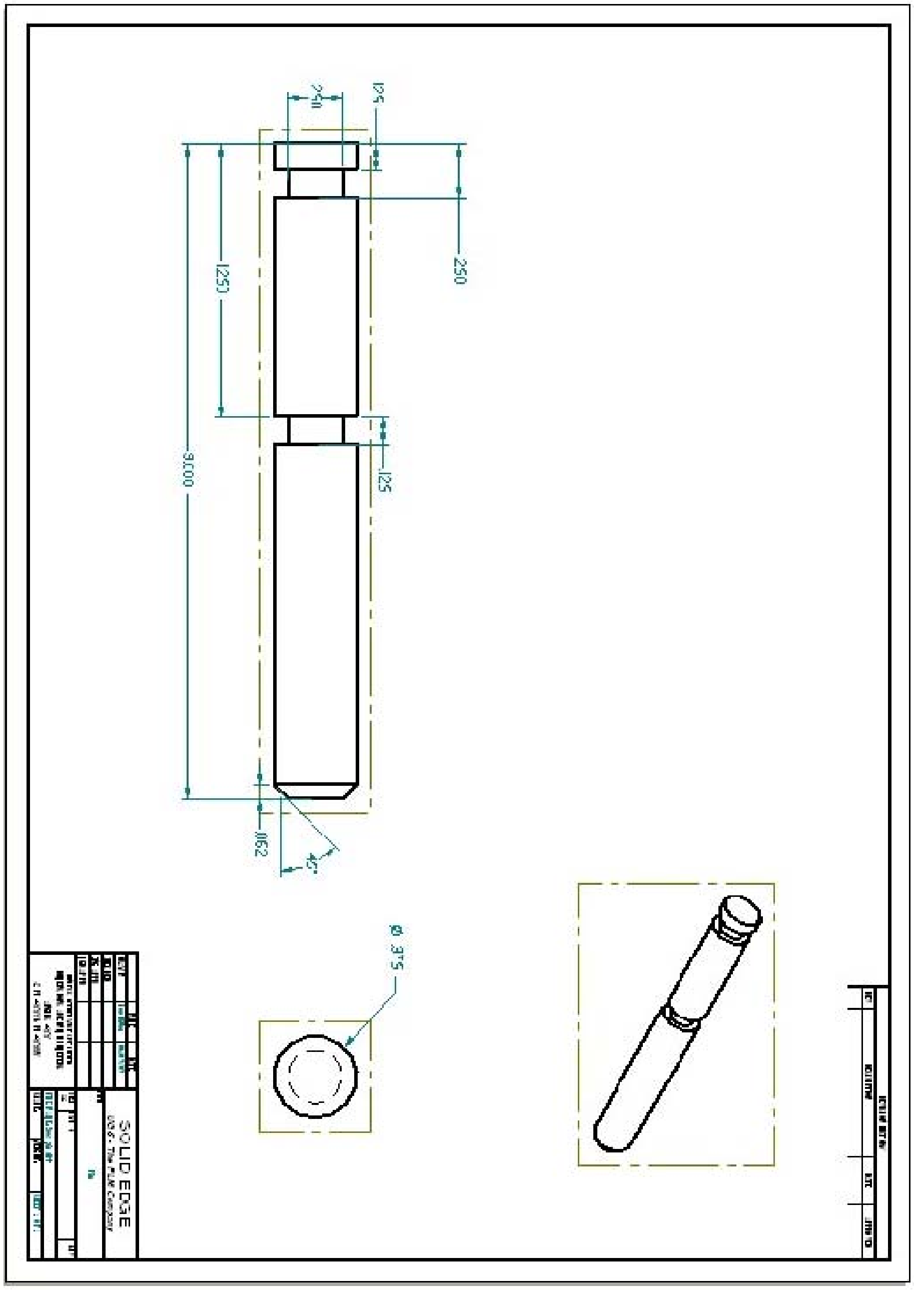
- 12”x12”x.125”
- 35A Soft Durometer rating
- 3760 PSI Tensile Strength
- 810% Stretch Limit
- FDA Compliant

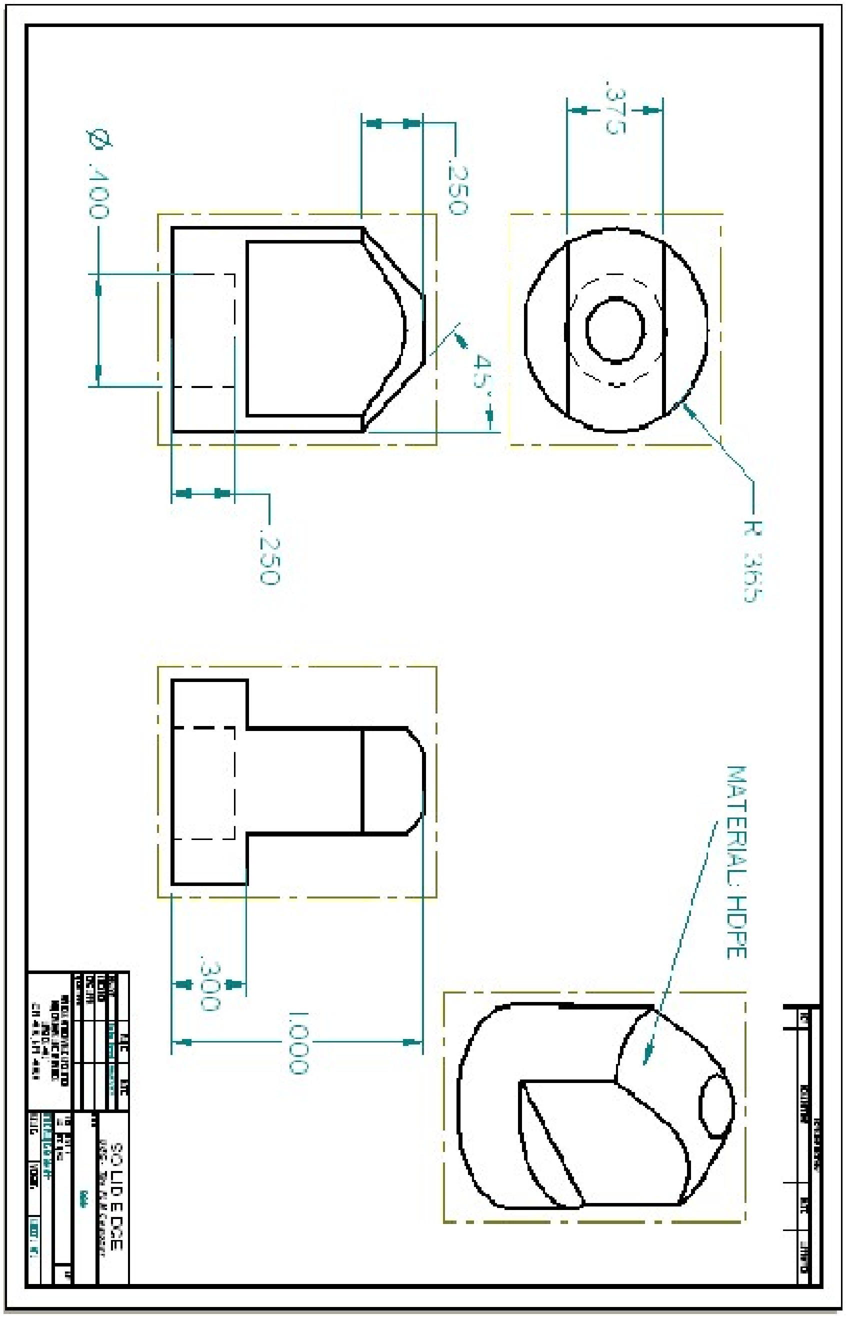
Appendix F. Part and Assembly Engineering Drawings



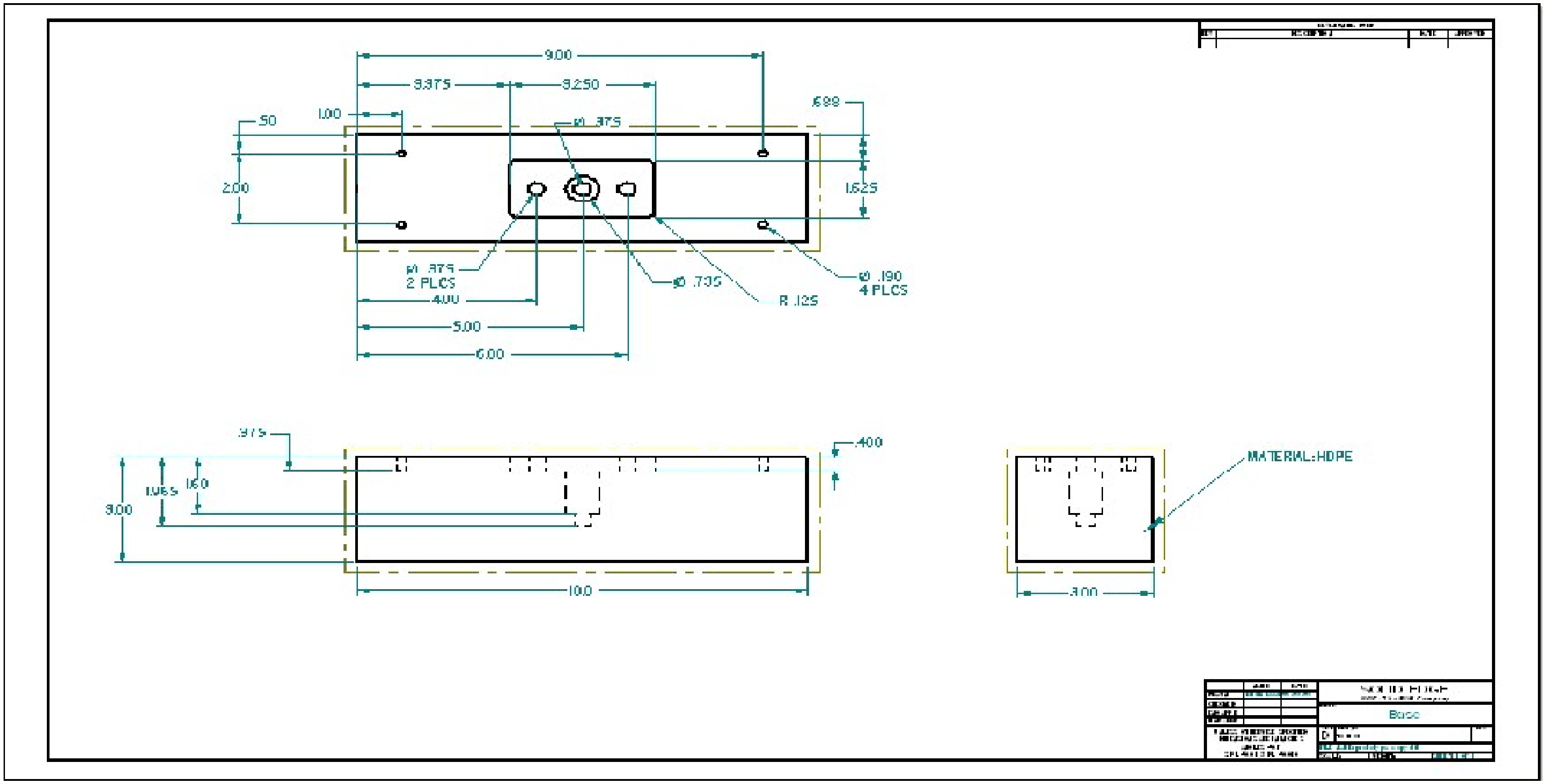

NOTES:
MATERIAL: HDPE
BREAK ALL SHARP EDGES
ALL TOLERANCES +/- 0.005 IN
Base


NOTES:
MATERIAL: HDPE
BREAK ALL SHARP EDGES
ALL TOLERANCES +/- 0.005 IN
SOLID EDGE

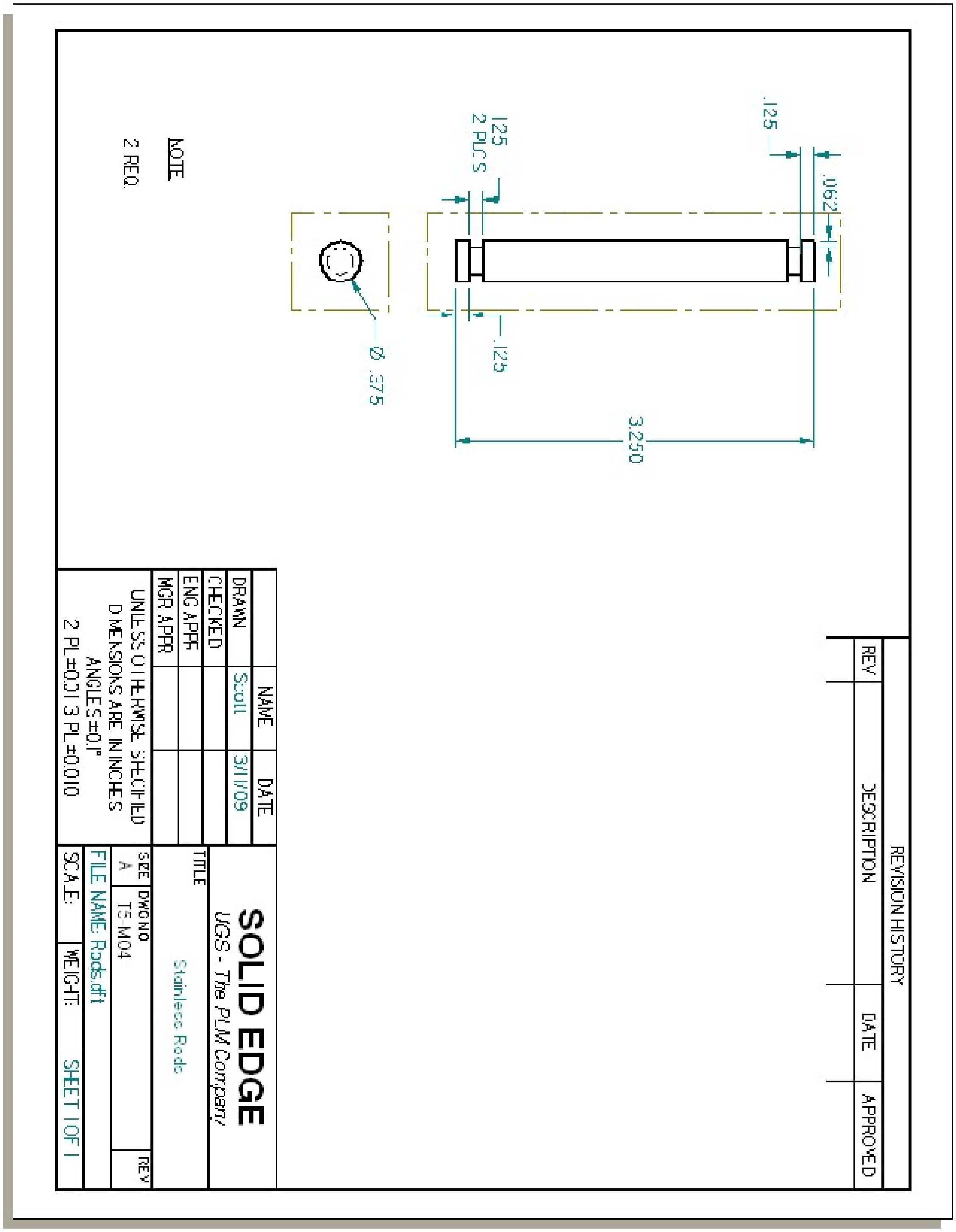

9.000
1.250
.250
.125
.062
45°
Ø .375
SOLID EDGE



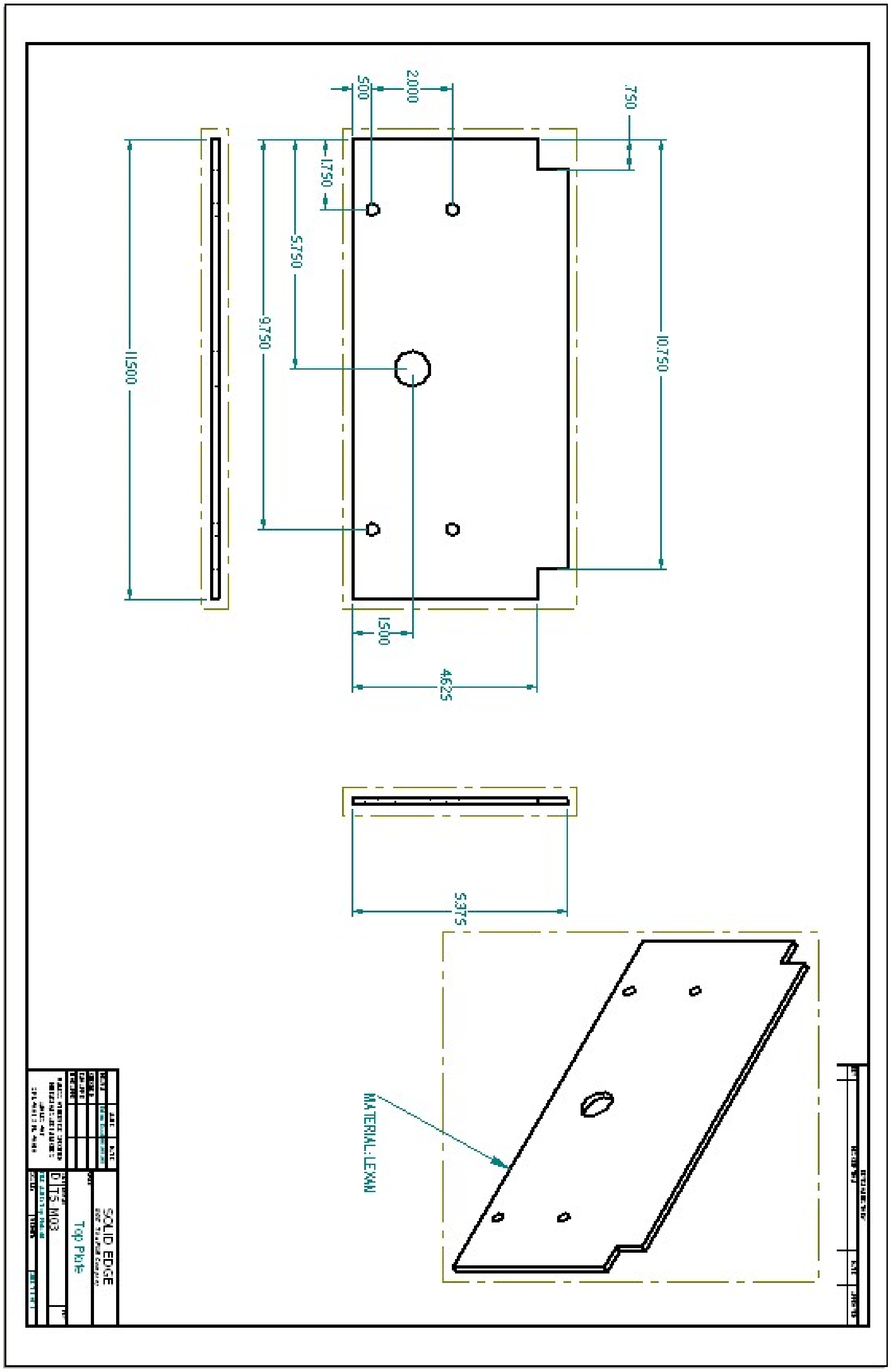
Ø .400
.250
.375
45°
.250
R .365
MATERIAL: HDPE
.300
1.000
SOLID EDGE

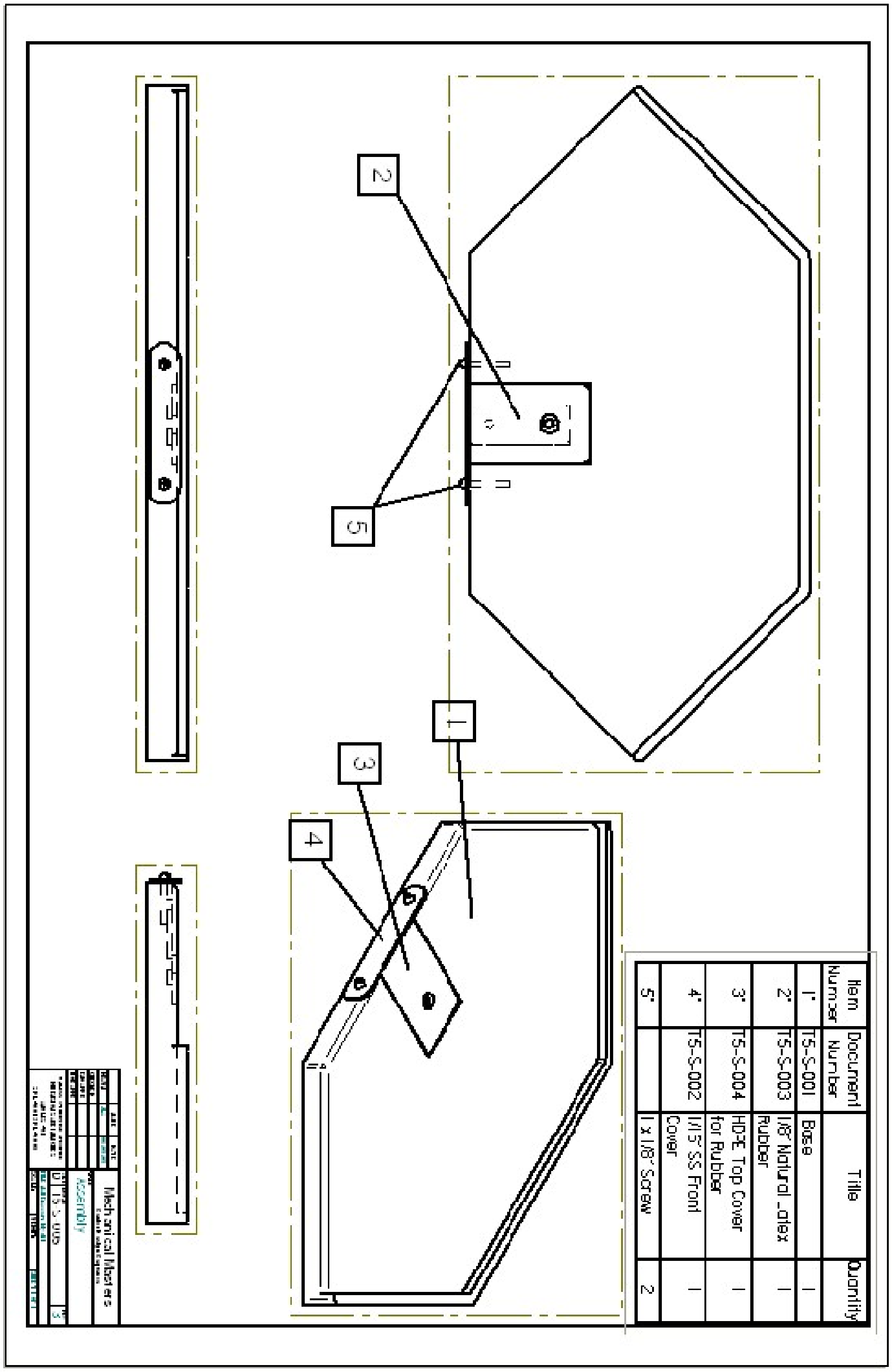


9.00
3.375
3.250
.50
1.00
.699
Ø .375
2.00
1.625
Ø .375
2 PLCS
4.00
5.00
6.00
Ø .735
R .125
Ø .190
4 PLCS
.375
.400
3.00
1.065
.160
10.0
3.00
MATERIAL:HDPE
SOLID EDGE
Base

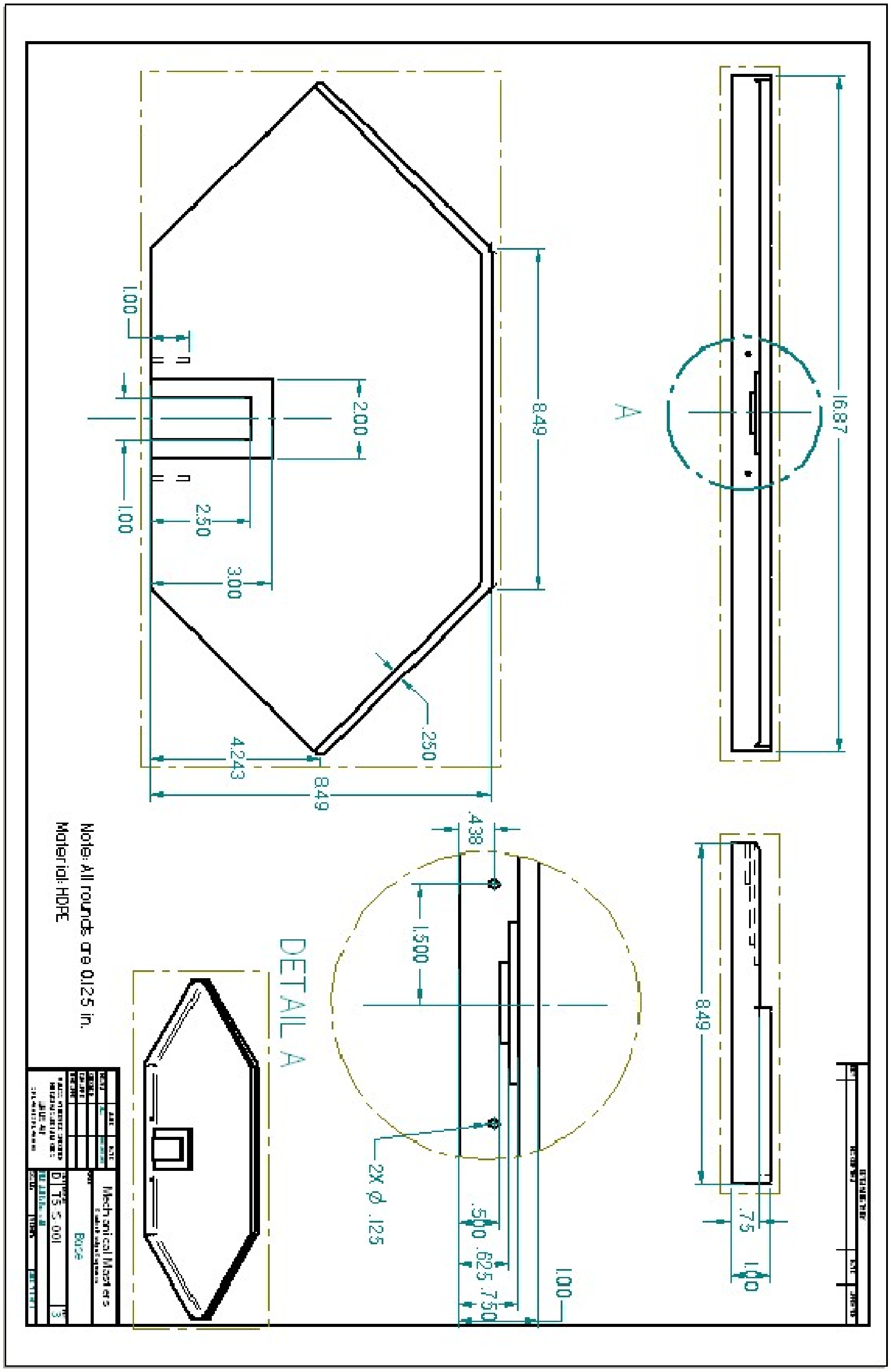


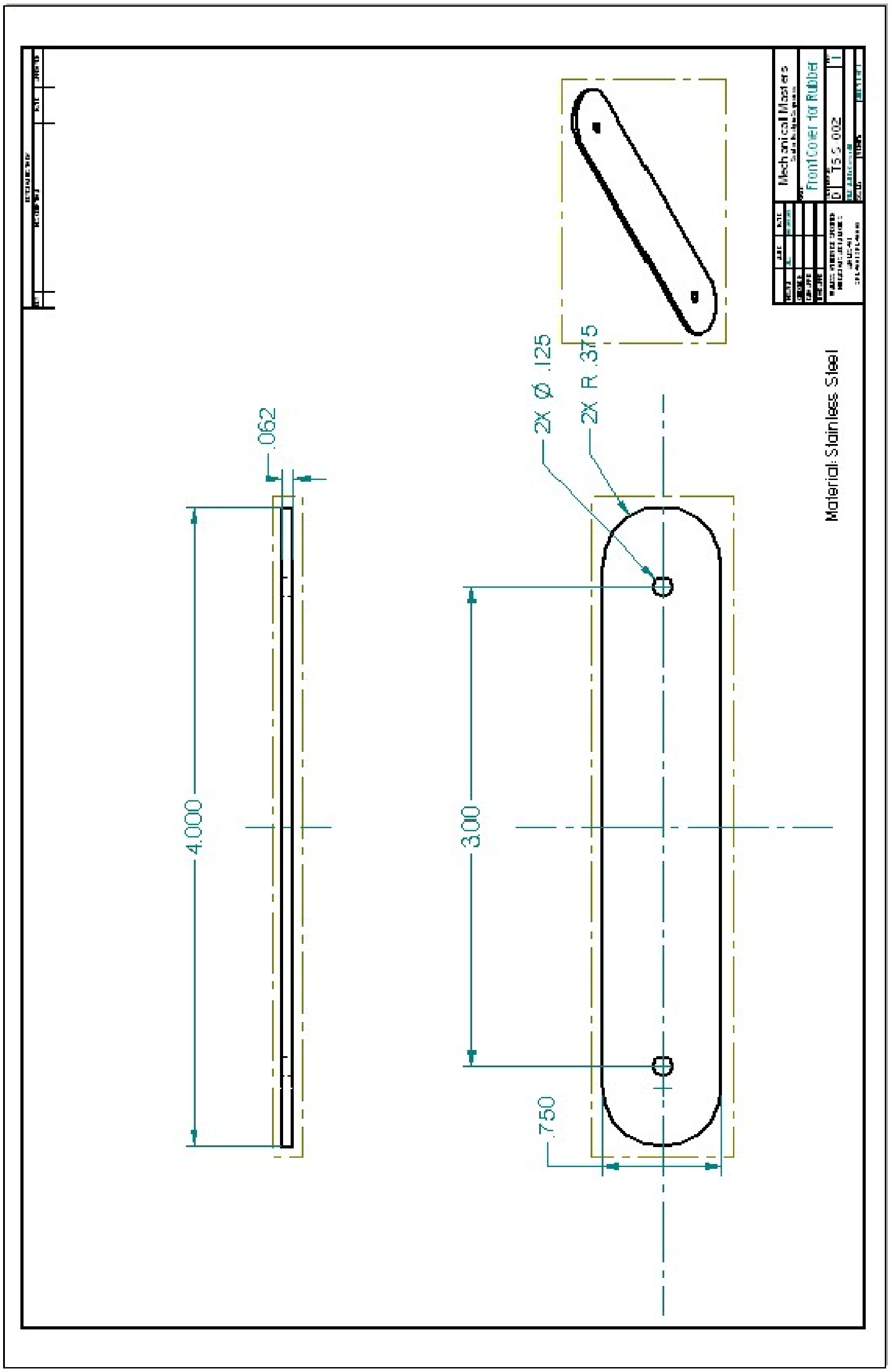
.125
.062
.125
2 PLCS
.125
Ø .375
3.250
NOTE
2 REQ.
REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
NAME
DATE
DRAWN
Scott
3/11/09
CHECKED
ENG APPR
MGR APPR
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ANGLES ±0.1°
2 PL ±0.01 3 PL ±0.010
SOLID EDGE
UGS - The PLM Company
TITLE
Stainless Rods
SIZE
A
DWG NO
TS M04
REV
FILE NAME: Rods.dft
SCALE:
WEIGHT:
SHEET 1 OF 1

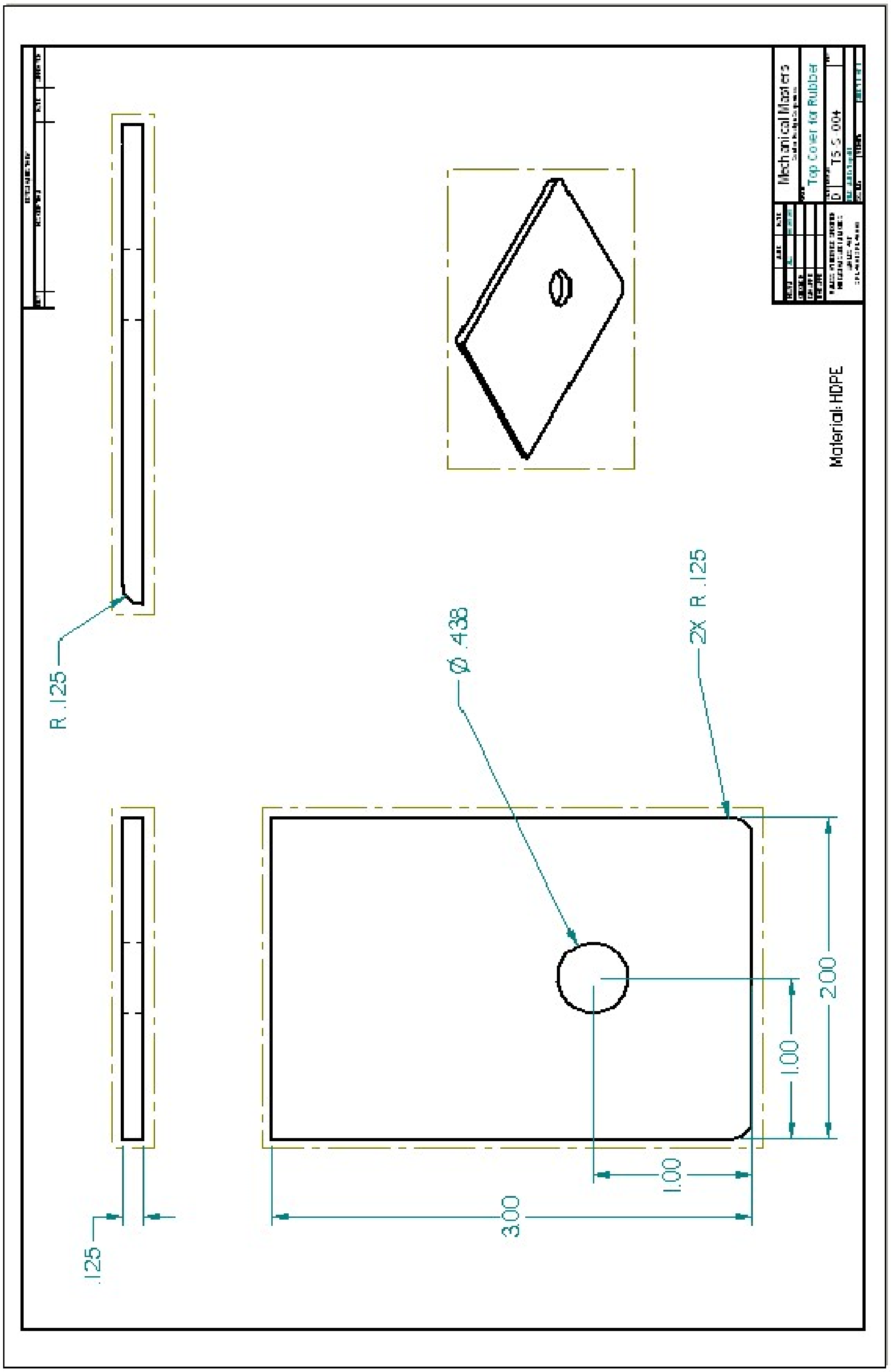

.500
2.000
.750
1.750
5.750
9.750
11.500
10.750
1.500
4.625
5.375
MATERIAL: LEXAN
SOLID EDGE
Top Plate

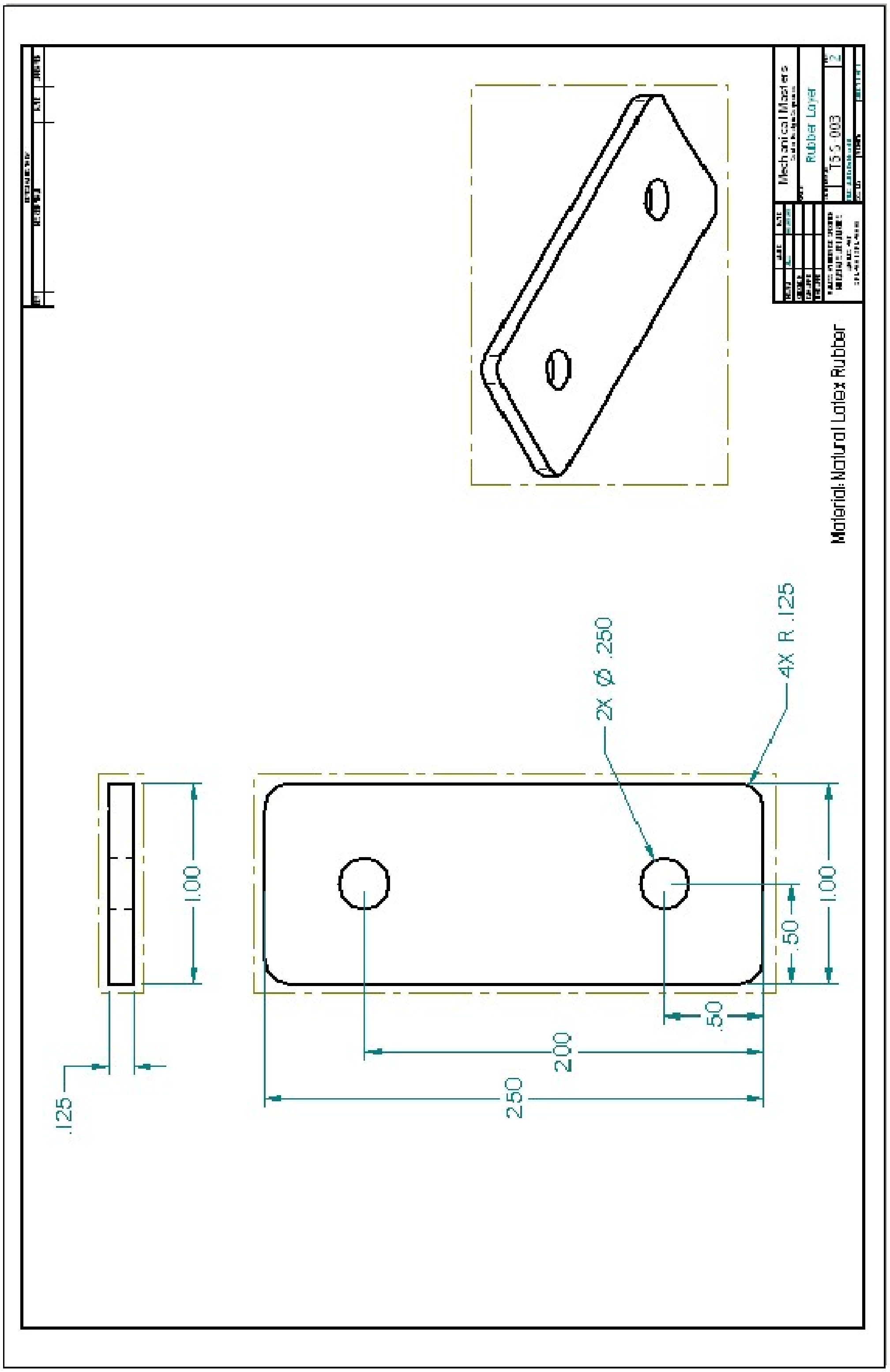


2
5
1
3
4
Item Number
Document Number
Title
Quantity
1
T5-S-001
Base
1
2
T5-S-003
1/8" Natural Latex Rubber
1
3
T5-S-004
HDPE Top Cover for Rubber
1
4
T5-S-002
1/1.5" SS Front Cover
1
5
1 x 1/8" Screw
2
Mechanical Masters
Assembly


DETAIL A
A
Note: All rounds are 0.125 in.
Material: HDPE
Mechanical Masters
Base
16.87
8.49
8.49
8.49
2.00
1.00
1.00
2.50
3.00
4.243
.250
.438
1.500
2X ⌀ .125
.500
.625
.750
1.00
.75


Mechanical Masters
Front Cover for Rubber
TSS 002
Material: Stainless Steel
2X Ø .125
2X R .375
.062
4.000
3.00
.750


R .125
Ø .438
2X R .125
2.00
1.00
1.00
3.00
.125
Material: HDPE
Mechanical Masters
Top Cover for Rubber
TS S 004



Mechanical Masters
Rubber Layer
Material: Natural Latex Rubber
2X Ø .250
4X R .125
1.00
.50
.50
2.00
2.50
1.00
.125